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Preliminary Development of Alternative Remediation Technologies and Identification of Data Needs for OU 7-13/14 Feasibility Study

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Project/Task: Engineering Support of OU 7-13/14 RI/FS Study

Subtask: Identification of Data Needs

TITLE: Preliminary Development of Alternative Remediation Technologies and Identification of Data Needs for OU 7-13/14 Feasibility Study

SUMMARY: This EDF contains the results of a preliminary study to identify containment and treatment processes that may be evaluated in the OU 7-13/14 feasibility study and to identify the data needed to screen and evaluate different technologies, processes and alternatives. Data sheets were developed for process options falling under nine technology catagories. To better identify data gaps for different processes, data was reviewed for thirteen processes.

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PRELIMINARY DEVELOPMENT OF ALTERNATIVE REMEDIATION TECHNOLOGIES AND IDENTIFICATION OF DATA NEEDS FOR OU 7-13/14 FEASIBILITY STUDY

1.0 INTRODUCTION

This Engineering Design File (EDF) contains the results of a preliminary study to identify alternative technologies for remediation of the Radioactive Waste Management Complex (RWMC) Subsurface Disposal Area (SDA) pits and trenches, and identify data needed to evaluate these technologies. Information on SDA waste gathered in the Historical Data Task[1] (HDT) and other documents was reviewed for waste quantities, waste composition and waste forms. In addition, the Preliminary Scoping Risk Assessment[2] (PSRA) and the Human Health Contaminant Screening Analysis[3] present preliminary guidance regarding waste contaminants, both radiological and nonradiological, that pose the greatest risks to human health. This information provides a basis for containment or treatment requirements. Based on these containment/treatment requirements, sets of data needs for different categories of technologies were developed. Finally information was obtained on a few treatment systems and subsystems and reviewed in order to better identify data that would be needed in the evaluation of process options for remediation of the SDA pits and trenches.

An Interim Action Activity involving the remediation of Pit 9 of the SDA, is currently in the design stage. A proof of principle (POP) test for key components in the Pit 9 treatment system has been completed and a larger, more complete limited production test (LPT) is planned. A primary objective of the Pit 9 remediation is to obtain data to support the pits and trenches Remedial Investigation/Feasibility Study (RI/FS).[4] While many similarities exist between the waste of Pit 9 and the waste buried in other pits and trenches and data from the Pit 9 Limited Production Test will be invaluable in evaluating the feasibility of one system for remediation of the SDA, there are important differences:

1. The total waste and contaminated soil in the total pits and trenches could be as much as 50 times greater than that of Pit 9, thus a larger scale process may be required.

2. Records of waste in Pit 9 are more complete than for most other pits and trenches, thus the uncertainties regarding waste composition, type and form are greater for the pits and trenches as a whole than for Pit 9. Also, some types of waste not suspected in Pit 9 are known to be present in other pits and trenches. Examples include gas cylinders, pyrophoric materials, and fuel casks. Thus a greater level of process flexibility may be required to remediate the pits and trenches.

3. Waste retrieved from Pit 9 that contains less than 10 nCi/g TRU is not treated but returned to the pit. A Preliminary Scoping Risk Assessment[2] has found that the greatest risk is from a non-TRU radionuclide, Sr-90, and that other non-TRU radionuclides such as C-14 and Cs-137 also have relatively high risks. Thus the pits and trenches remediation objectives will be broader in scope than those of Pit 9. Also, the pits and

trenches remediation objectives will likely include treatment to destroy or stabilize hazardous constituents, which will not be done in the Pit 9 remediation for the portion of retrieved material with less than 10 nCi/g TRU.

4. Fifteen hazardous constituents are known to exist in the pits and trenches that are not known to be present in Pit 9.[a] Some of these materials, such as ammonia cylinders or NaK, present handling and processing requirements beyond the scope of the Pit 9 treatment process design.

The objectives of remediation of the SDA pits and trenches have not been defined at this time. In lieu of more specific objectives, it will be assumed for this review that the general objective is to prevent migration of hazardous constituents of SDA waste, both radiological and nonradiological, into the environment so as to pose a risk to human health.

A full range of remediation alternatives has been defined by Grigg and is included as Appendix A in EDF. Alternatives cover responses of no action, institutional control, in-situ containment or stabilization, retrieval and repackaging, and retrieval and ex-situ processing. A wide range of containment, isolation, and treatment options are included under these response categories. All of these process options should be reviewed in the feasibility study for SDA pits and trenches remediation. However, this review is based on the assumption that mitigation of risks from hazardous constituents in the SDA waste will require processing wastes into a more stable form. Thus only in-situ and ex-situ treatment processes are reviewed.

[a] This is based on a comparison of the nonradiological contaminants for the pits and trenches, as reported in table S-1 of the Comprehensive Inventory (Reference 1) with the Historical Data Task Pit 9 inventory of hazardous chemicals, Table 2 of *Comparison of the Pit 9 Project Inventory Against the Corresponding Portion of the Historical Data Task Inventory: Background, Progress to Date and Proposed Plans*, November 2, 1994. The fifteen contaminants are:

	kg
Ammonia	780
Anthracene	0.2
Antimony	0.45
"Benzine"	4
Cerium chloride	510
Formaldehyde	140
Hydrazine	1.8
Magnesium	9,000
Magnesium fluoride	140
Nickel	2.2
Sodium	68
Sodium-Potassium	17,000
Terphenyl (Santo wax)	450
Toluene	190
Trimethylolpropane-triester	1,200

Other hazardous chemicals of unknown quantities are suspected to be present in the pits and trenches that are not known to be present in Pit 9, including organophosphates, organic acids, nitrocellulose, dibutylethylcarbutol, magnesium, nitrobenzene, PCBs, magnesium oxide, and beryllium oxide.

2.0 CHARACTERISTICS OF SDA WASTE AND DERIVED TREATMENT FUNCTIONAL AND OPERATION REQUIREMENTS

2.1 Total Waste and Contaminated Soil Volume and Weight

Remediation of the SDA requires containment or treatment of contaminants primarily within two media, soil and solid waste. Smaller amounts of liquid wastes and sludges are buried in the SDA. Liquids disposed of in one pit, the acid pit, were poured directly into the pit, resulting in contaminated soil.

Various studies report total quantities of waste buried at the SDA. Historical records of waste disposal show 129,503 m^3 (4,573,000 ft^3) of low-level waste and 61,989 m^3 (2,189,000 ft^3) of TRU waste buried at the SDA over the years 1952-1984.[5] According to these figures, the total waste would be 6.8 million cubic feet. An Environmental Evaluation report also gives a value of 2,200,000 ft^3 for TRU waste emplaced in the SDA, but reports only 2,000,000 ft^3 of waste present as of 1982 because of retrieval efforts from 1974-1978.[6] Arrenholz and Knight, in a more recent report that seeks to evaluate all previous ones, cite values of 63,364.1 m^3 (2,237,600 ft^3) of TRU waste from Rocky Flats and 5,778.8 m^3 (204,070 ft^3) of TRU waste from other sources, for a total of 69,142.9 m^3 (2,442,000 ft^3) of TRU waste.[7]

For this study the total volume of waste was assumed to be 6,800,000 ft^3. This total was obtained by rounding the value reported in the historical records for low-level waste to 4,600,000 ft^3, adding 2,400,000 ft^3 of TRU waste base on the value cited in Arrenholz and Knight, and subtracting 200,000 ft^3 of waste that was retrieved and placed in storage. Assuming an average waste density of 40 lb/ft^3, the total weight of the waste would be 270 million pounds.

Arrenholz and Knight cite volumes of 7.7 million cubic feet, 8 million cubic feet, and 12.1 million cubic feet of wastes and contaminated soil in the TRU pits and trenches. Subtracting the volume of TRU waste from these three figures gives a estimate for contaminated soil between 5.5 and 9.9 million cubic feet for the TRU pits and trenches. Arrenholz and Knight evaluate discrepancies between these numbers and favor the larger one because of the degree of detail and the method used in its calculation. The value of 12.1 million cubic feet was obtained by adding waste container volumes, volumes of soil added with waste, overburden volumes, underburden volumes, and subsidence volumes for the 9 pits and 10 trenches known to contain TRU waste. A breakdown of these volumes is given in Table 1.

In order to estimate the amount of contaminated soil for all the pits and trenches, totals from Table 1 were prorated by the ratio of total waste (6.8 million cubic feet) to TRU waste (using the value of 2.326 million cubic feet as per Table 1). These volumes are shown in column 2 of in Table 2. Also shown are very rough estimates of contaminated overburden and contaminated soil from migration of contaminates between pits or trenches. The contaminated overburden was assumed to be 10% of the total overburden, and the contaminated soil between pits and trenches was assumed to be 10% of the total pit and trench volume minus the overburden.

Table 1. Volume data for TRU waste pits and trenches[a] (Guay 1989)

Location	Excavated Volume (ft^3)	Waste Container Volume (ft^3)	Soil Volume (ft^3)	Overburden Volume (ft^3)	Underburden Volume (ft^3)	Subsidence Volume (ft^3)
T 1	81,243	16,897	64,346	30,563	NA	0
T 2	86,932	6,801	80,131	26,544	NA	0
T 3	90,658	12,375[b]	78,284	26,664	NA	689
T 4	93,828	17,788	76,040	26,808	NA	750
T 5	112,362	18,176	94,457	29,245	NA	0
T 6	91,982	15,475	76,507	26,856	NA	1,800
T 7	87,278	10,729	76,549	29,093	NA	0
T 8	97,752	14,143[b]	83,610	26,880	NA	156
T 9	83,633	13,237[b]	70,396	28,891	NA	0
T 10	91,474	9,107[b]	82,368	26,904	NA	923
P 1	379,135	81,819	297,316	107,884	169,532	0
P 2	1,020,359	418,357	602,002	425,975	544,852	455
P 3	368,394	102,059	266,335	236,150	70,845	0
P 4	955,309	388,494	566,815	787,343	367,427	0
P 5	796,729	286,612	510,117	368,236	100,428	18
P 6	447,515	223,898	223,617	409,313	191,013	0
P 9	342,416	150,690	191,726	256,812	149,807	353
P 10	1,052,941	538,865	514,076	784,084	526,471	0
P 11	NA	NA	NA	NA	NA	NA
P 12	NA	NA	NA	NA	NA	NA

Total volume of pits and trenches = 6,279,940 ft^3
Total volume of waste containers = 2,325,251 ft^3
Total volume of contaminated soil = 9,734,456 ft^3
(obtained by summing soil, overburden, underburden, and subsidence volumes.)
Total volume of contaminated wastes and soils. = 12,059,707 ft^3

a. Does not include wastes retrieved during Early Waste Retrieval and Initial Drum Retrieval projects.

b. Waste container volumes reflect 50% reduction in cardboard box volume due to compaction.

Table 2. Estimates of contaminated soil at the SDA

	TRU pits and trenches[a] (cubic feet)	Total pits and trenches[b] (cubic feet)	Based on 18 ft ave. depth (cubic feet)
1. Waste volume	2,325,522	6,800,000	(6,800,000)
2. Soil intermingled with waste	3,954,692	11,563,000	
3. Underburden	2,120,375	6,200,000	
4. Overburden	3,654,245	10,685,000	
5. Subsidence	5,144	15,000	
6. Total, lines 1+2+3	8,400,589	24,563,000	16,196,000 ⚠
7. Contaminated overburden[c]	365,425	1,069,000	675,000 ⚠
8. Contaminated soil between pits/trenches[d]	840,059	2,456,000	1,620,000 ⚠
9. Total, lines 6+7+8	9,606,073	28,088,000	18,491,000
10. Total, lines 2+3+7+8	7,280,055	21,288,000	11,691,000
11. Total, lines 4+5+6+8	12,900,037	37,719,000	
12. Total, lines 2+3+4+5+8	10,574,515	30,919,000	

[a] Lines 1-5 from K. P. Guay, *Preparation of Soil Distribution in Trenches 1-10 and Pits 1-6, 9, and 10*, EG&G Engineering Design File BWP-ISV-011, undated.
[b] Prorated from TRU volumes by the factor 6.8/2.326
[c] Assumed to be 10% of line 4
[d] Assumed to be 10% of line 6

Line 10 in Table 2 are estimates of the total contaminated soil assuming a minimal amount of the overburden (10%) and also that a relatively small amount of soil between pits and trenches would be processed. Line 12 shows the estimated soil assuming that all of the overburden is processed. Lines 9 and 12 are the corresponding total volumes of waste plus soil.

Table 2 breaks down soil estimates into different categories so that as remediation objectives become more defined, appropriate soil rates can be selected. If only soil from TRU pits and trenches was to be processed, for example, the volume would be about 7 million cubic feet, compared to 21 million cubic feed for all pits and trenches.

The estimated total volume of soil vaults is 122,394 ft^3.[2]

A separate recent study[8] by Meachum recalculated areas and volumes for the SDA pits and trenches, and are shown in Table 3. Meachum's values shows a total area of pits 1-6, 9 and 10 plus trenches 1-10 of 658,187 ft^2, about 5% greater than the area for these pits and trenches calculated by Guay.

However, the pit and trench volumes calculated by Meachum are much lower than those of Guay. Meachum's volume calculations are based on a depth of 14.2 feet for all pits (except pit 7) and trenches, defined as "the average depth of the surficial soils in the SDA", while Guay used depths calculated from the mean surface elevation and mean basalt surface elevation for each pit and trench. No basis for this depth of 14.2 ft could be located. Using Guay's elevations results an average pit depth, without overburden, of 13.4 feet, and with overburden, of 19.3 feet. The PSRA uses pit and trench surface areas from Meachum, but calculates volumes based on an average depth of 8.3 ft, based on the difference between 14.2 ft and an assumed cover thickness of 5.9 ft. Hubbell[19] reports an average depth of the SDA to the basalt of 16 ft, assuming a land surface elevation of 5010 ft. SDA contour maps[20-21] indicate an average surface elevation closer to 5012-5014 ft.[a] The third column of Table 2, line 6, shows a total volume of soil and waste calculated using the total surface area of Meachum and a depth of 12 ft (18 ft total depth, based on a average surface elevation of 5012 ft, minus 6 ft overburden). If these assumptions are correct (surface elevation of 5012 ft, overburden of 6 ft), the volume of contaminated soil in pits and trenches would be 9.4 million cubic feet, or, adding 0.5 ft overburden and 10% for contaminated soil between pits and trenches, about 12 million cubic feet.

The large differences between the values of columns 2 and 3 suggest that a more analysis is warranted. A better value of land elevation can be obtained from the SDA contour maps, and various SDA studies reviewed to confirm the assumed depth of cover.

Pending additional evaluation to resolve these discrepancies, a volume of 10 million cubic feet of contaminated soil will be assumed for all the pits and trenches. Using a bulk density of 100 lb/ft^3 for INEL soil, the weight of 12 million cubic feet of soil is 1.2 billion pounds. Because of past compaction efforts at the SDA, the density could be greater than what was assumed, and hence the total weight would also be greater.

2.2 Processing Rate Requirements

For this study, the minimum processing rate is based on treatment of only TRU waste (2.2 million cubic feet) and contaminated soil (7 million cubic feet), a 10-year processing time, and 200 days/year stream factor. With these assumptions, the required processing rate is 110 tons per day. For retrieval operations, the required minimum rate is 160 tons per day. Treatment of waste and contaminated soil from all pits and trenches would require a processing rate of 360 tons per day for treatment and 580 tons per day for retrieval. Throughput rates for systems in which feed waste and soil is separated to be treated in different units would require, for each unit, a fractional rate of these totals according to the proportion of material in each separated fraction.

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[a] In a phone talk with Joel Hubbell July 19, 1995, he confirmed that the surface elevation of 5010 feet was a rounded value.

Table 3. Areas and volumes of pits and trenches from Meachum[8]

Pit	Area, ft^2	Volume, ft^3	Trench	Area, ft^2	Volume, ft^3
1	24,913	353,765	19	9,905	140,651
2	78,425	1,113,635	20	7,000	99,400
3	41,830	593,986	21	2,625	37,275
4	111,732	1,581,284	22	2,653	37,673
5	108,754	1,544,307	23	3,093	43,935
6	54,984	780,773	24	2,947	41,847
7	300	1,200	25	7,000	99,400
8	31,294	444,375	26	3,115	44,233
9	45,541	646,682	27	7,007	99,499
10	111,732	1,586,594	28	3,094	43,935
11	24,859	352,998	29	2,422	34,392
12	29,910	424,722	30	7,014	99,599
13	19,290	273,918	31	3,101	44,034
14	40,704	577,997	32	2,457	34,889
15	74,805	1,062,231	33	7,007	99,499
16	22,246	315,893	34	2,280	103,376
17	66,587	945,535	35	7,007	99,499
18	49,652	705,058	36	8,603	122,163
Acid	21,291	302,332	37	7,000	99,400
			38	6,419	91,150
Trench			39	6,993	99,301
			40	7,287	103,475
1	8,043	114,211	41	7,000	99,400
2	8,015	113,813	42	7,952	112,918
3	7,777	110,433	43	6,664	94,629
4	7,812	110,930	44	3,500	49,700
5	8,155	115,801	45	7,959	113,018
6	7,826	111,129	46	6,699	95,126
7	8,120	115,304	47	7,966	113,117
8	7,826	111,129	48	6,685	94,927
9	8,610	122,262	49	7,728	109,738
10	8,092	114,906	50	6,601	93,734
11	6,279	89,162	51	7,987	113,415
12	12,502	177,528	52	6,349	90,156
13	5,439	77,234	53	8,050	114,310
14	10,969	155,760	54	6,370	90,454
15	5,495	78,029	55	8,134	115,503
16	10,801	153,374	56	8,134	115,503
17	4,270	60,624	57	6,342	90,056
18	7,175	101,885	58	6,447	91,547

2.3 Waste Inhomogeneity and Complexity

Table 4 lists items known to be contained in SDA waste. While the following section attempts to estimate relative amounts of waste types, Table 4 is presented to underscore the great diversity and complexity of the waste.

2.4 General Waste Types

Table 5 shows an estimate of waste types present in RWMC stored waste, and quoted by Arrenholz and Knight (Reference 7, Table 11) as applicable to buried waste with some exceptions.

Table 5. Weight and volume fractions of stored waste at the RWMC.

Category	Weight Percent	Volume Percent
Combustibles	20.1	42.0
Sludge	32.7	18.0
Metals	22.2	8.6
Concrete, brick, particulate	7.9	4.5
Nonmetals and glass	2.8	4.1
Other (including "unknown")	14.3	22.8

The major exception noted by Arrenholz in applying this breakdown to buried waste is that the buried waste may contain more building materials than the stored waste.

A breakdown of Rocky Flats waste, which amounts to slightly more than 30 vol% of the total buried waste, by category is given in the Appendix D of the Comprehensive Inventory,[1] and shown in Table 6.

Weights and volumes given in the Comprehensive Inventory data sheets for the Rocky Flats metals waste stream indicate a void volume of nearly 95%, which is suspiciously high. Edinborough shows a density of stored metal waste of 11.6 times that of the Rocky Flats waste (from Table 11 of Reference 7). Thus the weight fraction of metal waste shown in Table 6 may be low.

Table 4. Wastes known to be present in SDA waste.[a]

Construction and Demolition Material	Lumber, wallboard, concrete, steel plate, ducting, electrical wires, fuse boxes, roofing material, floor tile, insulation, lead sheet, lead brick, asphalt paving materials, soil, sand, gravel, steel stairways, ladders, plexiglas, leaded glass, glove boxes, asbestos, Benelex
Laboratory equipment and materials	Hoods, laboratory benches, desks, chairs, cabinets, glassware, plastic tubing, plastic and glass bottles, solutions stabilized in concrete or plaster, vermiculite, steel-copper crucibles, rubber hose, acid carboy, uranium film sampler, glovebox gloves, syringes, gas cylinders
Process equipment and materials	Air compressor, tanks, heat exchangers, tube bundles, condensers, piping, flanges, valves, ion exchange resins and columns, demineralizer, pumps and pump parts, motors, continuous air monitors, air conditioner, furnace coke, carbon baffles, HEPA filters, Raschig rings, electronic tubes and instruments, control panels, dissolver pots, drums of organic solvent
Nuclear reactor components, fuel,[b] and radioactive sources	Irradiated hardware, core structural components, fuel scraps, fuel rods, graphite cuttings, reactor core, beryllium reflectors, Ra-226 and other sources, reactor vessel, fuel end pieces, 39 Co-60 wires in concrete, irradiated fuel powder and pellets (see note b), Pu-coated disks
Maintenance equipment and scrap metals	Hand tools, metal-working machines, drill presses, cranes, hoists, welders, oil and grease, metal filings, abrasive wheels, lathes, drum of machine coolant, scrap metals (Ag, Al, Be, Cd, Cu, Fe, K, Mg alloy, Mg-Th, Na, NaK, Pb, Sn, depleted Uranium, Zr and Zr alloys, others), backhoe parts
Decontamination Materials	Paper, rags, plastic bags and sheet, floor sweepings, brooms, steel wool, coveralls, hardhats
Miscellaneous	Sewer sludge, garbage, tires, lunchbox, animal tissue, carcasses, feces, botulinus-contaminated meat, jet engine, dump truck, trailers, forklift, pickup trucks, tanker, magnesium fluoride slag, solidified $CeCl_3$ solution, boric acid crystals, solidified evaporator sludge, contaminated mud, office equipment, lead-acid batteries, mercury batteries, barrels of Santo-R wax, tires, safe, camera, radios, casks, concrete cask with steel liner filled with solidified sludge

[a] Expanded from Table 9 in Arrenholz and Knight (Reference 8) based on waste descriptions in the Comprehensive Inventory (Reference 1). No claim is made as to the completeness of this list.

[b] Waste identified as fuel is not spent fuel per the definition of DOE Order 5820.2A.

As a rough check on relative amounts of different types of waste buried in the SDA, the descriptions of the individual waste streams in the Comprehensive Inventory were used to categorize waste streams as "metal", "combustible", or "other". For some streams a breakdown of relative amount of each type of waste was available, and for many others the relative amount of each type was estimated. Using this approach, the waste was determined to be approximately 35 vol% combustible, 20 vol% metal, and 45 vol% other, or, in terms of weight percent, 37% metal, 16% combustible, and 47% other. A summary of the waste breakdown by these three methods is given in Table 7.

Table 6. Rocky Flats waste buried at the SDA (based on 1971-1981 data).

Category	Weight Percent[a]	Volume Percent
Metals	17.5	38.57
Combustibles	25.3	26.26
Uncemented sludges	43.3	11.72
Filters	2.7	9.71
Mixed Waste	1.6	3.94
Concrete, brick	2.6	3.52
Glass	1.1	2.04
Particulate	1.1	1.53
Molds and crucibles	0.8	0.95
Cemented sludge	3.5	0.94
Glovebox gloves	0.4	0.54
Benelex, plexiglas	0.1	0.24
Resins	-	0.02
Salts	-	0.02

[a] Weights for all categories except combustibles, sludges and benelex taken from data sheets for SDA Rocky Flats wastes contained in Reference 1. Density for benelex assumed the same as for glass, densities for combustibles and sludge taken from Reference 7, Table 11.

Table 7. SDA waste by category, weight percent

	Based on Stored Waste	Based on Rocky Flats	Based on Descriptions of Individual Waste Streams	Range of Estimates	Best Estimate
Metal	22	18	37	18-37	30
Combustible	20	25	16	16-25	20
Other	58	57	47	47-58	50

2.5 Waste Container Types and Physical Form

Table 8 gives a breakdown of container type by waste location for the TRU pits and trenches. Drums include 55-gal, 40-gal, and 30-gal, the "standard" wooden box size was 7 ft by 4 ft by 4 ft, but other sizes were uses as well, including 7 ft by 4 ft by 50 in, and 7 ft by 4 ft by 52 in. Cardboard boxes include 28 in by 28 in by 16 in, 24 in by 24 in by 14 in, 24 in by 24 in by 16 in, 24 in by 24 in by 18 in, and 24 in by 24 in by 28 in.

Table 8. Waste Containers (from Reference 10)

Waste Area	Drums	Estimated Number of			Total
		Wooden Boxes	Cardboard Boxes	Other Containers	
Pit 1	8,285	152	2,173	2	10,612
Pit 2	34,480	1,048	3,547	443	39,518
Pit 3	6,684	202	3,309	62	10,256
Pit 4	31,467	624	2,020	268	34,379
Pit 5	19,652	919	970	102	21,643
Pit 6	13,912	590	3,523	36	18,061
Pit 9	3,937	520	1,932	72	6,461
Pit 10	27,101	2,311	914	295	30,621
Trench 1	3,376	-	-	1	3,377
Trench 2	1,045	4	-	-	1,049
Trench 3	1,242	6	1,423	-	2,671
Trench 4	2,416	1	-	-	2,417
Trench 5	2,541	-	-	-	2,514
Trench 6	2,283	1	-	-	2,284
Trench 7	1,497	-	-	-	1,497
Trench 8	1,654	793	-	-	2,447
Trench 9	1,769	1	2	-	1,772
Trench 10	1,236	-	7	-	1,243
Total	164,577	6,378	20,613	1281	192,849

Any treatment process must not only be able to process the waste containers, but also the various large items known to be buried in the SDA, including truck beds, trailers, reactor vessels, heat exchangers, tanks, glove boxes, lathes, and at least one crane, forklift, air compressor, dump truck, safe and jet engine.

Based on the use of cardboard containers for a significant fraction of the waste, the practice of direct disposal of liquids and the deterioration of wooden boxes and breaching of metal drums found in retrieval efforts, it can be assumed that a large fraction of the original containers do not provide containment of the waste. However, it should be assumed that some drums of liquids are still intact, thus placing the requirement on any retrieval, drum handing, and shredding steps to be able to process drums of potentially flammable liquids.

Based on proration of the totals in Table 8 according to the waste volume ratio, the entire SDA would contain about 480,000 drums, 20,000 wooden boxes, 60,000 cardboard boxes, and 4,000 other containers.

2.6 Nonradiological contaminants

Table 9 lists estimated quantities of nonradiological contaminants known to be present in the SDA waste and, for reference, also for Pit 9. While only a small subset of this list may be determined in the risk assessment to have substantial risks or have high hazard quotients, the entire list is given for completeness. Certain components, while not contaminants of concern for the SDA remediation, may be subject to land-disposal or other restrictions under RCRA. Also, treatment technologies need to be reviewed relative to the entire list to identify any chemical interactions that could interfere with a given process.

Table 9. Quantities of nonradiological contaminants in Pit 9 and the SDA[a]
All values are kg except where stated

Halogenated organics	Pit 9	SDA	Ratio, SDA/Pit 9
1,1,1 trichloroethane	9,100	110,000	120
1,1,2 trichloro-1,2,2 trifluoroethane	97	9,100	94
Carbon tetrachloride	11,000	120,000	11
Chloroform, grams	0.6	37	59
Methylene chloride	160	14,000	88
Polychlorinated biphenyls (PCB)		unknown	
Tetrachloroethylene	2,500	27,000	11
Trichloroethylene	9,700	100,000	10
Nonhalogenated organics			
1,4-bis(5-phenyloxazol-2-yl)benzene		unknown	
3-methylcholanthrene		unknown	
Acetone	0.7	110	169
Alcohols		unknown	
Anthracene		0.2	
Benzene		unknown	
Benzine		4	

Butanol	1.1	99	90
2-Butanone	0.4	32	95
Dibutylethylcarbutol		unknown	
Diisopropylfluorophosphate		unknown	
Ethanol	0.3	22	76
Ether		unknown	
Formaldehyde	-	140	-
Methanol	2.4	220	92
Methyl isobutyl ketone	120	8,900	74
Nitrobenzene		unknown	
Nitrocellulose		unknown	
Organic Acids		unknown	
Organophosphates		unknown	
Terphenyl (Santo wax)	-	450	
Toluene	-	190	
Trimethylolpropane-triester	-	1,200	
Tributyl phosphate	13	1,000	77
Versenes[b]		unknown	
Xylene	5.2	850	163

[b] chelating agents containing ethylenediaminetetraacetic acid

Metals

Antimony, grams	-	450	-
Beryllium	18	15,000	833
Cadmium	6	1,600	286
Chromium, grams	0.3	1,000	3700
Copper		unknown	
Lead	5,000	580,000	116
Magnesium	-	9,000	
Manganese		unknown	
Mercury		unknown	
Nickel	-	2.2	
Silver, grams	9	5,900	641
Sodium	-	68	
Sodium-Potassium	-	1,700	
Zirconium & Zr alloys	910	25,000	27

Acids			
Aqua regia, grams	0.5	31	62
Hydrofluoric	99	7,600	80
Nitric	630	50,000	79
Sulfuric	1.4	120	86
Inorganic compounds			
Aluminum nitrate nanohydrate	2,500	190,000	76
Ammonia	-	780	
Asbestos (Mg, Ca, Fe silicates)	2	1,200	545
Beryllium oxide		unknown	
Cerium chloride	-	510	-
Copper nitrate, grams	4	330	77
Cyanide		unknown	
Hydrazine	-	1.8	
Lithium hydride		unknown	
Lithium oxide		unknown	
Magnesium fluoride	-	140	
Magnesium oxide		unknown	
Mercury nitrate nanohydrate	11	810	74
Potassium chloride	1,200	20,000	17
Potassium nitrate	26,000	450,000	17
Potassium phosphate	990	10,000	10
Potassium sulfate	1,200	20,000	17
Sodium chloride	2,300	40,000	17
Sodium cyanide, grams	43	940	22
Sodium hydroxide, grams	7	150	22
Sodium nitrate	52,000	900,000	17
Sodium phosphate	1,200	20,000	17
Sodium sulfate	2,300	40,000	17
Uranyl nitrate	2.9	220	76

[a] List of contaminants and quantities for the SDA taken from the Comprehensive Inventory (Reference 1), Table S-1. Information for Pit 9 taken from the Historical Data Task Pit 9 inventory of hazardous chemicals, Table 2 of *Comparison of the Pit 9 Project Inventory Against the Corresponding Portion of the Historical Data Task Inventory: Background, Progress to Date and Proposed Plans*, November 2, 1994.

According to the Preliminary Scoping Risk Assessment,[2] the nonradiological contaminants of potential concern (COPC) are ammonia, asbestos, beryllium, cadmium, hydrofluoric acid, lead, mercury, nitrates, nitric acid, tributyl phosphate, and uranium. The Human Health Contaminant Screening Analysis for the SDA (unpublished at this time) has identified the following nonradiological contaminants as having the highest total risk or hazard quotient:

	Total Risk	Total Hazard Quotient
Asbestos	1E-05	-
Hydrazine	4E-06	-
Total nitrate	-	2E+02
Mercury	-	2E+01
Acetone	-	2E+01
Carbon tetrachloride	6E-04	2E+01
Cadmium	4E-08	1E+01
Uranium	-	7E+00
Lead	-	6E+00
Sodium cyanide	-	6E-01
Tetrachloroethylene	-	5E-01
2-Butanone	-	4E-01
Beryllium	2E-03	2E-01
Methylene chloride	3E-05	1E-01

All of the categories of Table 9 except acids are represented in this shorter list, including halogenated organics, nonhalogenated organics, metals, and inorganic compounds.

The following requirements are derived from or related to the nonradiological contaminants known to be present in SDA waste:

1. Destruction of hazardous halogenated organic materials with 99.9999% efficiency for efficiency for PCBs, 99.99% for others (This is based on RCRA standards, and would likely only apply to ex-situ thermal treatment processes).

2. Destruction of hazardous nonhalogenated organic materials with 99.99% efficiency. (This is based on RCRA standards and would likely only apply to ex-situ thermal treatment processes).

3. Ability to adequately handle and process volatile organic constituents (VOCs). The majority of VOCs can be assumed to be present in pits 2,4,5,6,9, and 10. ⚠

4. Ability to handle and process RCRA-hazardous metals (arsenic, barium, cadmium, chromium, mercury, lead, selenium, and silver) into acceptable waste forms. Lead is present in the waste as bricks, sheets, gloves, batteries and possibly other forms. The other RCRA-hazardous metals are also present in different forms, including metallic, inorganic, and possibly organometallic.

5. Ability to process and convert soils contaminated with acids (HF, sulfuric, nitric, aqua regia) into stable waste forms

6. Ability to process gas cylinders of ammonia

7. Ability to convert asbestos into a nonhazardous stable waste form

8. Ability to convert soil contaminated with oxidizers (nitrates) and reducing agents (hydrazine) into stable waste forms

9. Ability to process hazardous constituents at concentrations in soil from very low (ppm level) to nearly 100%.

10. Ability to safely handle and process pyrophoric or reactive material including metallic sodium, NaK, UAlX powder, Zr and Zr alloy chips and fines

11. Ability to process beryllium (mostly scrap metal, possibly some oxide and/or sludge) and uranium (scrap and other metal, irradiated fuel,[a] and absorbed oxide, hydroxide, nitrate or other forms on waste forms such as filters, sludge, rubble, soil and combustible material) into acceptable waste forms.

12. Ability to process tributyl phosphate and other organophosphorus compounds in soil into acceptable final waste forms.

2.7 Radionuclide contaminants

Table 10 presents the radiological contaminants found to be contaminants of potential concern in the PSRA[2]. Isotopes not on this list but included on the Final Human Health Retention List of the Human Health Contaminant Screening Analysis[3] are: Am-243, Be-10, Cf-252, Cl-36, Cm-244, Hf-175, Hf-181, I-129, Ir-192, Mn-53, Na-22, Nb-94, Sn-117m, Sn-119m, Th-232, U-234, U-236, Yb-164. A more recent evaluation of risks showed 33 radionuclides with risks greater than 10^{-7}, and includes all shown on Table 10 except Cs-134, Eu-155, Fe-55, Mn-54, Sb-125, Te-125m and Th-228. Additional contaminants on this recent list are: I-129, Tc-99, Cl-36, U-234, Am-243, U-236, Na-22, Th-232, Cm-244, Th-229, and Th-230. A complete list of all known radionuclides present in the SDA can be found in Reference 1, Table S-2.

Relative to treatment, radionuclide contaminants can be grouped in three categories, shown in Table 11. Contaminants listed in Table 11 include only those that have recently been determined to pose a risk of 10^{-7} or higher (from Reference 3), and are listed in Table 11 by element.

[a] Waste identified as irradiated fuel is not spent fuel per the definition of DOE Order 5820.2A.

Table 10. Radiological contaminants found to be contaminants of potential concern (COPC) in the PSRA.

	Curies, at time of emplacement[a]	Grams, at time of emplacement
Am-241	150,000	46,000
C-14	21,000	4,700
Co-60	2,400,000	2,100
Cs-134	2,200	0.17
Cs-137	620,000	7,100
Eu-152	240	1.1
Eu-154	2,800	19
Eu-155	11,000	8.6
Fe-55	1,100,000	440
H-3	1,100,000	110
Mn-54	180,000	22
Nb-94	51	270
Ni-59	4,500	59,000
Ni-63	690,000	11,000
Np-237	1.9	2,700
Pu-238	2,600	150
Pu-239	66,000	1,100,000
Pu-240	15,000	66,000
Pu-241	410,000	3,600
Pu-242	0.99	250
Ra-226	59	60
Sb-125	140,000	130
Sr-90	450,000	3,200
Te-125m	-	-
Th-228	-	-
U-232	8.4	0.39
U-233	1.1	120
U-235	6.8	3,200,000
U-238	90	270,000,000

[a] Curies from Reference 1, Table S-2

Table 11. Radiological Contaminants by Categories

1. Elements forming volatile compounds: H, I, Cl, C
2. Transuranic elements: Am, Pu, U, Np, Cm, Th
3. Others: Sr, Cs, Ni, Tc, Nb, Ra, Co, Eu, Na

The following requirements are derived from or related to the radiological contaminants known to be present in SDA waste:

1. Ability to adequately detect and handle different levels of radioactivity, from background levels to irradiated fuel[a] and radioactive sources. Thus a treatment process must not only be able to remove low levels of, for example, TRU contamination in soil, but also detect and process high concentrations of both fuel[a] and depleted uranium. (need to quantify activity variation with data from RWMIS)

2. Ability to handle/process carbon-14 into acceptable final waste form.

3. Ability to handle/process tritium into acceptable final waste form.

4. Ability to handle/process radioactive halogens.

5. Ability to handle, separate and process Sr-90 into an acceptable waste form.

6. Ability to handle, separate and process Cs-137 into an acceptable final waste form.

7. Ability to handle, separate and process Am, U, and Pu into an acceptable final waste forms

8. Ability to process Ni, Tc, Nb, Ra, Co, Eu, and Na into acceptable final waste forms.

[a] Waste identified as "irradiated fuel" or "fuel" is not spent fuel per the definition of DOE Order 5820.2A.

3.0 REMEDIATION ALTERNATIVES

A review of technologies and processes was made to identify data needs for the feasibility study for OU 7-13 pits and trenches. According to EPA guidance documents for feasibility studies, the three screening criteria for evaluating process options are effectiveness, implementability and cost.

3.1 Technology & Process Option Data Sources

Information on remediation technologies is available from computer databases, technical reports containing reviews and summaries of technologies, technical and commercial literature, and vendors of remediation technology. Data from the Pit 9 Limited Production Test will also be important in evaluating process options for remediation of OU 7-13/14.

3.1.1 Databases

The U.S. Environmental Protection Agency (EPA) has generated and maintains three data bases to support remediation projects. The Vendor Information System for Innovative Technology[11] (VISITT) contains information on 27 bench-scale, 49 pilot-scale, and 201 full-scale technologies. The data base includes the description, limitations, waste applications, project data, cost estimates, technical references, contacts, and other information for each technology. While most of the technologies are full-scale, the database is limited to innovative technologies.

The EPA also maintains other databases. The Alternative Treatment Technology Information Center (ATTIC) computer database provides abstracts on all types of hazardous waste treatment technologies, and links to several other treatment databases. Another EPA database is the Treatability Data Base that contains information on 1217 chemical compounds and 15,800 sets of treatability data.

The Techcon program includes access to technical and business information on domestic and foreign sourcesfor mature, proven, and commerically-available technology.

3.1.2 Reviews and Summaries

Technology Logic Diagrams have been prepared for INEL Waste Area Groups (WAG).[12] Technologies are grouped into categories of characterization, retrieval, biological and chemical treatment, thermal and physical treatment, caps and barriers, decontamination, dismantlement, material disposition, and robotics/automation. Alternative technologies are outlined for each Operable Unit, with information on the status, science and technology needs and implementation needs of alternative technologies. Data sheets for each technology are contained in a separate volume.

Treatment technology data was collected in a pre-engineering study for a Mixed and Low Level Waste Treatment Facility at the INEL.[13] The report contains data on input streams, output streams, advantages, limitations, and the status of each technology. In another study of alternative treatment technologies for DOE mixed waste, life-cycle costs were determined for 19 different treatment systems.[14,15]

Several studies have reviewed or evaluated treatment options for waste buried at the SDA.[16-18]

3.1.3 Technical and Commercial Literature and Contacts

Other technical data is available in waste treatment handbooks, engineering textbooks, environmental journals, EPA documents, reports from other DOE sites, and commercial literature. A bibliography of resource documents contained in the EPA guidance document for conducting feasibility studies under CERCLA, and is included in this EDF as Appendix B.

3.1.4 Pit 9 Interim Action Remediation Design and Test Documents

Data generated in the design, proof of principle, limited production test, and operation of the Pit 9 remediation project should be used in the feasibility study to evaluate the Pit 9 process relative to alternatives for remediation of OU 7-13/14.

3.2 Process Option Data Needs

For the feasibility study, data is needed for "technology types," defined as general categories of technologies, for the one criteria of implementability; for process options (single technologies that treat a single media) in the three screening criteria categories of effectiveness, implementability and cost; and finally for a reduced set of alternatives (combinations of process options to remediate entire site) in the nine evaluation criteria of

1. Overall Protection of Human Health and Environment
2. Compliance with ARARs
3. Long-term Effectiveness and Permanence
4. Reductions in Toxicity, Mobility and Volume Through Treatment
5. Short-term Effectiveness
6. Implementability
7. Cost
8. State Acceptance
9. Community Acceptance.

To enable a thorough screening of process options, blank data sheets were developed for various groups of process options. Data sheets have specific questions regarding the screening criteria of effectiveness, implementability and cost, and well as space for contacts and references. In general, effectiveness must be measured against treatment objectives. As objectives become better defined, the data sheets should be updated.

3.2.1 Data Sheet for In-Situ Treatment Systems

In-situ technologies are considered as complete systems, and may consist of pretreatment steps, a grouting or vitrification system, offgas treatment and support systems, such as electrical power generation or transmission. Certain technologies such as bioremediation for specific contaminants or vapor vacuum extraction may be considered as subsystems in an overall in-situ system. However, the number of total in-situ systems is expected to be relatively small.

In the data sheet, effectiveness is evaluated in five categories: effectiveness in treatment of all types of medium and waste forms in the SDA pits and trenches, effectiveness in minimizing worker exposure, effectiveness in minimizing final waste quantities and emissions, effectiveness in destroying organic contaminants, and effectiveness in immobilizing radiological and inorganic contaminants. Implementability is based on the number and capacity of commercial and pilot facilities and demonstration results or plans.

Table 3-1. Data Sheet for In-Situ Treatment System

Technology Name(s):
Commercial Name:

Effectiveness (medium and waste types)

Applicable to	Yes	No
Contaminated soil		
Contaminated metal		
Combustible waste		
Cemented sludges, concrete, brick, etc.		
Uncemented sludges		
Salts		
Nitrates		
Other salts		
Mixed waste types		
Drums of liquids		
Aqueous liquids		
Acids		
Organic liquids		
Halogenated		
Nonhalogenated		
Organophosphates		
Gas cylinders		
High activity waste		
Pyrophoric materials		
Lead wastes		

Asbestos

Other restrictions on waste types and pretreatment requirements:

Effectiveness (worker exposure during treatment):

Effectiveness (final waste quantity and composition)

Offgas characteristics/treatment system:
Liquid wastes: (types and relative rates and compositions)
Solid wastes: (types and relative rates and compositions)

Effectiveness (contaminant destruction)

Destruction efficiency for PCBs:
Destruction efficiency for halogenated organics:
Destruction efficiency for nonhalogenated organics:

Effectiveness (contaminant immobilization)

Fate of volatile radionuclides: (^3H, $^{14}CO_2$, halogens...)
Fate of volatile and semivolatile metals: (Hg, Pb, Cd, As...)
Will the following contaminants be processed into a stabilized waste form?
- RCRA-metals
- Reducing agents (hydrazine, ammonia)
- Oxidizing agents (nitrates)
- Sr-90
- Cs-137
- TRU elements

Is further stabilization required for any solid wastes:

Implementability

Commercial Capacity and number of commercial facilities:
Demonstrated Capacity or Demonstration Plans:

Costs

Demonstration and Testing:
Capital:
Operating:
- Utility Requirements:
  - Electricity:
  - Fuel (type & rate):

Water:
Other:

Vendors, Contacts, References:

3.2.2 Data Sheet for In-Situ Isolation Technologies

Isolation technologies would add physical barriers between the waste and the environment, in part or in whole. Effectiveness is evaluated in terms of coverage, resistance of the barrier to penetration of water or biological life from outside the barrier, resistance of the barrier to release of contaminants to surrounding air, soil, or groundwater, resistance to degradation, and worker exposure during construction and maintenance. Implementability is evaluated in terms of the number and type of projects that have used the technology and the results of demonstrations.

Table 3-2. Data Sheet for In-Situ Isolation Technology

Technology Name(s):
Commercial Name:

Effectiveness (coverage)

Size limitations of barrier, including height, depth into soil, and horizontal capability
Location(s) of barrier

Effectiveness (penetration)

Biological penetration (plants and animals)
Water penetration

Effectiveness (contaminant release to the environment)

VOC release to atmosphere
Radionuclide migration to groundwater and aquifer
Hazardous organics migration to groundwater and aquifer
Migration of contaminants to soils outside of SDA

Effectiveness (resistance to degradation)

Chemical stability
Resistance to biodegradation
Resistance to moisture
Resistance to freezing/thawing cycles

Design earthquake magnitude
Expected lifetime

Effectiveness (worker exposure during construction and maintenance):

Implementability

Commercial usage (number, size, type)
Hazardous waste sites:
Nuclear waste sites:
Demonstration projects or plans:

Costs

Demonstration and Testing:
Construction:
Maintenance:

Vendors, Contacts, References:

3.2.3 Data Sheet for Retrieval Technologies

Retrieval is a subsystem that would be required for any ex-situ process. Effectiveness is evaluated in terms of applicability to all the SDA waste forms, minimization of worker exposure to radiation, and minimal secondary waste from dust generated, contaminated equipment, chemicals or handling or packaging materials.

Table 3-3. Data Sheet for Retrieval Technology

Technology Name(s):
Commercial Name:

Effectiveness (Applicability to SDA waste media and forms)

Wet soil/sludge
Dry soil (including fines)
Waste containers - drums, boxes, casks
Large waste items - trucks, tanks, etc.
Radiological sources
Gas cylinders
Pyrophoric material
Wire cables

Effectiveness (worker exposure):

Remote Operations
Maintenance Operations
Bubble Suit Use
Use of various manipulators
Handling and sizing of large objects in the pits/trenches
Control Systems/Data Acquisition Systems/Vision systems
Dust generation

Effectiveness (secondary wastes):

Dust generation
Contamination control system capacity and approach
Large objects sizing system
Sorting ability
Funnel/conveyance/transport system

Implementability

Standard unit retrieval rate capabilities:
Demonstrated projects or demonstration plans
- Nuclear sites:
- Hazardous waste sites:
- Demonstration of remote operation:

Capabilities of support systems
- Contamination/air system:
- Water requirements:
- Fuel requirements:
- Local control rooms:
- Measurements - weights, volumes, air quality, flows, radioactivity

Costs

Demonstration and Testing:
Capital:
- Main system
- Support system

Operating:
- Major Utility Usages:

Vendors, Contacts, References:

3.2.4 Data Sheet for Pretreatment Technologies

Pretreatment steps include any sorting, sizing, or contaminant removal in order for a downstream process to properly function. Sorting could involve separation by phase, type, size, density or other means. Processes will typically involve physical separation but some processes may involve chemical reactions or separations. The data sheet below is intended to be general, and some parts may not apply to some pretreatment technologies.

Table 3-4. Data Sheet for Pretreatment Technology

Technology Name(s):
Commercial Name:

Effectiveness (medium and waste types)

Applicable to	Yes	No
Soil		
Metal		
Combustible waste		
Cemented sludges, concrete, brick, etc.		
Uncemented sludges		
Salts		
Nitrates		
Other salts		
Mixed waste types		
Drums of liquids		
Aqueous liquids		
Acids		
Organic liquids		
Halogenated		
Nonhalogenated		
Organophosphates		
Gas cylinders		
High activity waste		
Pyrophoric materials		
Lead wastes		
Asbestos		

Other restrictions on waste types:

Effectiveness (degree of separation)

Targeted separation(s):
Separation efficiency or efficiencies:

Effectiveness (degree of size reduction)

Target output size:
Size reduction efficiency:

Effectiveness (worker exposure during treatment and maintenance):

Dust generation:
Offgas generation:

Effectiveness (secondary waste quantities and composition)

Offgas/blanketing gas characteristics/rates:
Liquid wastes: (types and relative rates and compositions)
Secondary solid wastes: (types and relative rates and compositions)

Implementability

Commercial Capacity and number of commercial facilities:
Demonstrated Capacity or Demonstration Plans:

Costs

Demonstration and Testing:
Capital:
Operating:
Major Utility Requirements:

Vendors, Contacts, References:

3.2.5 Data Sheet for Decontamination Technologies

Decontamination involves physical, chemical, mechanical or thermal surface cleaning or removal. Bulk decontamination methods will be considered under the thermal treatment category.

Table 3-5. Data Sheet for Decontamination Technology

Technology Name(s):
Commercial Name:

Effectiveness (medium and waste types)

Applicable to	Yes	No
Large metal items		
Metal containers		
Small metal items		
Wood		
Concrete		
Plastic		
Composite Materials		
Bulk Lead		

Restrictions on waste types, forms or sizes:

Effectiveness (decontamination factors)

TRU elements:
Other radionuclides:

Effectiveness (worker exposure during operation):

Effectiveness (secondary waste quantities and composition)

Offgas characteristics/rates:
Liquid wastes: (types and relative rates and compositions)
Secondary solid wastes: (types and relative rates and compositions)

Implementability

Commercial Usage and processing rate capability:
Demonstration projects or plans:

Costs

Demonstration and Testing:
Capital:
Operating:

Major Utility Requirements:

Vendors, Contacts, References:

3.2.6 Data Sheet for Thermal Treatment and Oxidation Technologies

Thermal treatment includes incineration technologies, ex-situ vitrification and melter technologies, pyrolysis, gasification and thermal desorption technologies. Oxidation technologies include supercritical water oxidation, catalytic oxidation processes, electrolytic oxidation processes, photooxidation processes and others.

Table 3-6. Data Sheet for Thermal Treatment System

Technology Name(s):
Commercial Name:

Effectiveness (medium and waste types)

Applicable to	Yes	No
Contaminated soil		
Contaminated metal		
Combustible waste		
Cemented sludges, concrete, brick, etc.		
Uncemented sludges		
Salts		
Nitrates		
Other salts		
Mixed waste types		
Drums of liquids		
Aqueous liquids		
Acids		
Organic liquids		
Halogenated		
Nonhalogenated		
Organophosphates		
Gas cylinders		
High activity waste		
Pyrophoric materials		
Lead wastes		
Asbestos		

Other restrictions on waste types and pretreatment requirements:

Effectiveness (worker exposure during treatment):

Maintenance requirements:

Effectiveness (final waste quantity and composition)

Offgas characteristics/treatment system:
Liquid wastes: (types and relative rates and compositions)
Solid wastes: (types and relative rates and compositions)

Effectiveness (contaminant destruction)

Destruction efficiency for PCBs:
Destruction efficiency for halogenated organics:
Destruction efficiency for nonhalogenated organics:

Effectiveness (contaminant immobilization)

Fate of volatile radionuclides: (^3H, $^{14}CO_2$, halogens...)
Fate of volatile and semivolatile metals: (Hg, Pb, Cd, As...)
Will the following contaminants be processed into a stabilized waste form?
- RCRA-metals
- Reducing agents (hydrazine, ammonia)
- Oxidizing agents (nitrates)
- Sr-90
- Cs-137
- TRU elements

Is further stabilization required for any solid wastes:

Implementability

Commercial Capacity and number of commercial facilities:
Demonstrated Capacity or Demonstration Plans:

Costs

Demonstration and Testing:
Capital:
Operating:
- Utility Requirements:
  - Electricity:
  - Fuel (type & rate):
  - Water:
  - Other:

Vendors, Contacts, References:

3.2.7 Data Sheet for Chemical and Biological Separation Technologies

Chemical separation technologies are used to remove specific contaminants from the waste, such as organics from soil or transuranic elements from soil. Other processes that might be considered would be for removal of tritiated water and $^{14}CO_2$ from offgas or strontium from irradiated fuel.[a] Unit operations may involve extraction, dissolution, reactions, membrane separation, adsorption, absorption, distillation, precipitation or others.

Table 3-7. Data Sheet for Chemical or Biological Separation Technology

---

Technology Name(s):
Commercial Name:

Effectiveness (medium and waste types)

Applicable to	Yes	No
Soil		
Metal		
Combustible waste		
Cemented sludges, concrete, brick, etc.		
Uncemented sludges		
Salts		
Nitrates		
Other salts		
Mixed waste types		
Drums of liquids		
Aqueous liquids		
Acids		
Organic liquids		
Halogenated		
Nonhalogenated		
Organophosphates		
Pyrophoric materials		
Lead wastes		
Asbestos		

Other restrictions on waste types:

---

[a] Waste identified as irradiated fuel is not spent fuel per the definition of DOE Order 5820.2A.

Effectiveness (degree of separation and product quality)

Targeted separation(s):
Separation efficiency or efficiencies:
Level of contaminant remaining in/on solid product:
TRU (nCi/g):
Hazardous organics (ppm):
Other:
Is further stabilization required of solid product?
Is further treatment required of solid product?

Effectiveness (worker exposure):

Effectiveness (secondary waste quantities and composition)

Offgas characteristics/rates:
Liquid wastes: (types and relative rates and compositions)
Secondary solid wastes: (types and relative rates and compositions)

Implementability

Commercial Capacity and number of commercial facilities:
Demonstrated Capacity or Demonstration Plans:

Costs

Demonstration and Testing:
Capital:
Operating:
Major Utility Requirements:

Vendors, Contacts, References:

3.2.8 Data Sheet for Offgas Treatment Systems

Offgas treatment systems remove contaminants from gases present in waste or generated in treatment.

Table 3-8. Data Sheet for Offgas Treatment System

System Name:
Unit Operations:

Effectiveness (emission levels)

Total hydrocarbons
CO
Dioxins
Particulate less than 10 microns
Metal emissions
Radionuclides
HCl
SO_2
NO_x
NH_3

Effectiveness (worker exposure during treatment):

Effectiveness (solid and liquid secondary waste quantities and compositions)

Liquid wastes: (types and relative rates and compositions)
Solid wastes: (types and relative rates and compositions)

Effectiveness (contaminant immobilization)

Fate of volatile radionuclides: (^3H, $^{14}CO_2$, halogens...)
Fate of volatile and semivolatile metals: (Hg, Pb, Cd, As...)
Is further stabilization required for any solid wastes:

Implementability

Commercial Capacity and number of commercial facilities:
Demonstrated Capacity or Demonstration Plans:

Costs

Demonstration and Testing:
Capital:
Operating:
Major Utility Requirements:

Vendors, Contacts, References:

3.2.9 Data Sheet for Stabilization Technologies

Stabilization technologies transform wastes, primary or secondary, into a final form in which any remaining contaminants are in an immobilized form.

Table 3-9. Data Sheet for Stabilization Technology

Technology Name(s):
Commercial Name:

Effectiveness (medium and waste types)

Applicable to	Yes	No
Contaminated soil		
Contaminated metal		
Combustible waste		
Cemented sludges, concrete, brick, etc.		
Uncemented sludges		
Salts		
Nitrates		
Other salts		
Mixed waste types		
Drums of liquids		
Aqueous liquids		
Acids		
Organic liquids		
Halogenated		
Nonhalogenated		
Organophosphates		
Gas cylinders		
High activity waste		
Pyrophoric materials		
Lead wastes		
Asbestos		

Other restrictions on feed types or pretreatment requirements:

Effectiveness (worker exposure during treatment):

Effectiveness (final waste quantity and composition)

Offgas characteristics/treatment system:
Liquid wastes: (types and relative rates and compositions)
Solid wastes: (types and relative rates and compositions)

Effectiveness (contaminant immobilization)

Fate of volatile radionuclides: (^3H, $^{14}CO_2$, halogens...)

Fate of volatile and semivolatile metals: (Hg, Pb, Cd, As...)
Will the following contaminants be processed into a stabilized waste form?
RCRA-metals
Reducing agents (hydrazine, ammonia)
Oxidizing agents (nitrates)
Sr-90
Cs-137
TRU elements
Organics
Is further stabilization required for any solid wastes:

Implementability

Commercial Capacity and number of commercial facilities:
Demonstrated Capacity or Demonstration Plans:

Costs
Demonstration and Testing:
Capital:
Operating:
Major Utility Requirements:

Vendors, Contacts, References:

3.3 Representative Systems

A thorough evaluation of alternatives will be part of the OU 7-13/14 feasibility study. However, to develop better relative costs of different systems than could be obtained from technical and commercial sources, four representative alternatives were defined. These are shown schematically in Figures 1-4.

3.3.1 In-Situ Vitrification Treatment System

The in-situ vitrification alternative would consist of four subsystems, pretreatment, melting, offgas treatment, and support systems. In-situ treatment provides an alternative that treats the entire site, both soil and all forms of buried waste, by a the same process. Pretreatment would be needed to avoid or minimize undesirable transient conditions during melting, such as large evolutions of off-gas or large changes in offgas heat loadings. Pretreatment may be done to reduce void volumes in waste containers, to breech sealed containers of liquids, to remove excessive volatile organics, or to add flux material within waste volumes to achieve the desirable final product composition.

Figure 1

In-Situ Vitrification System

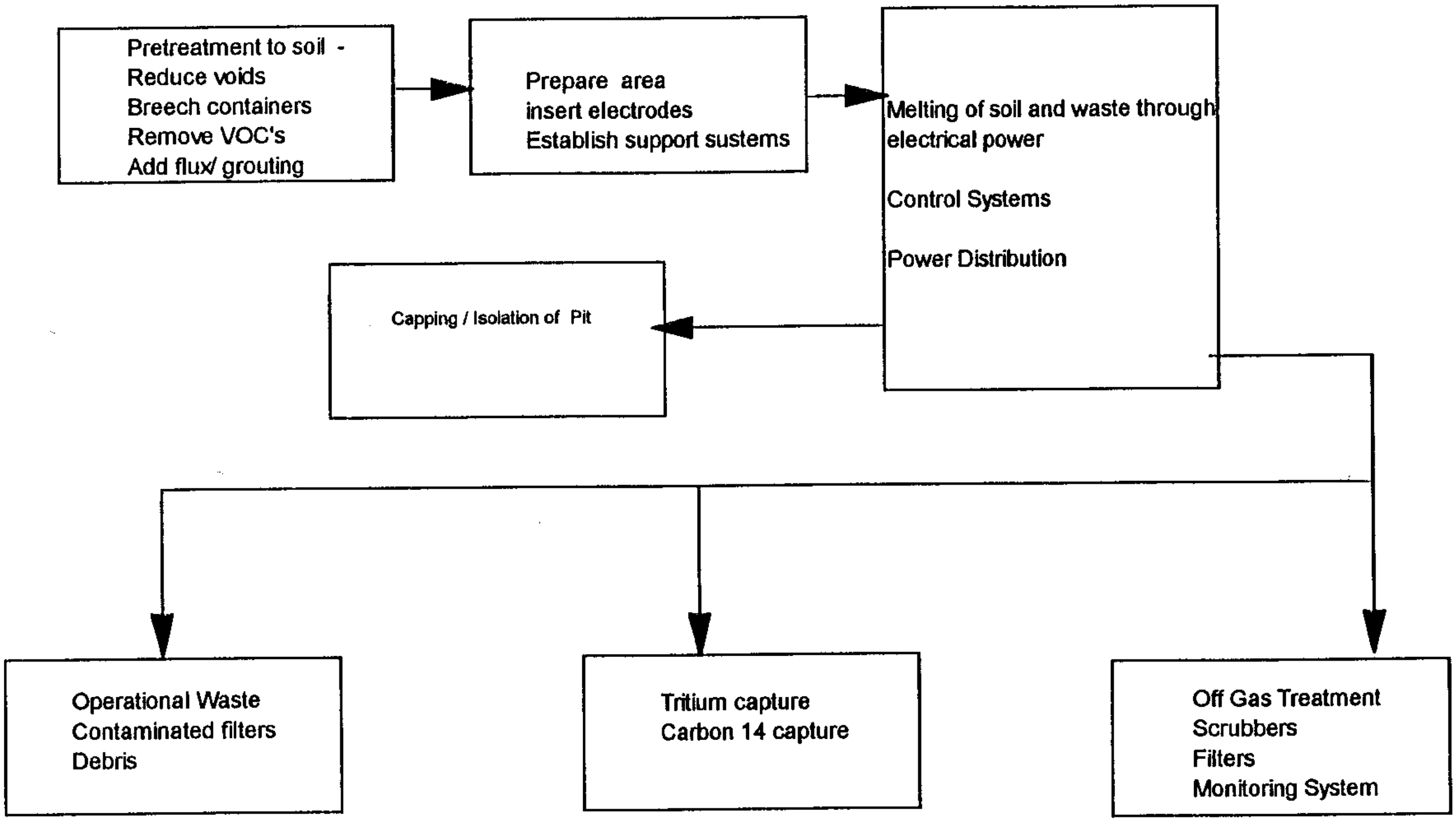


Figure 2

Ex-Situ Treatment System

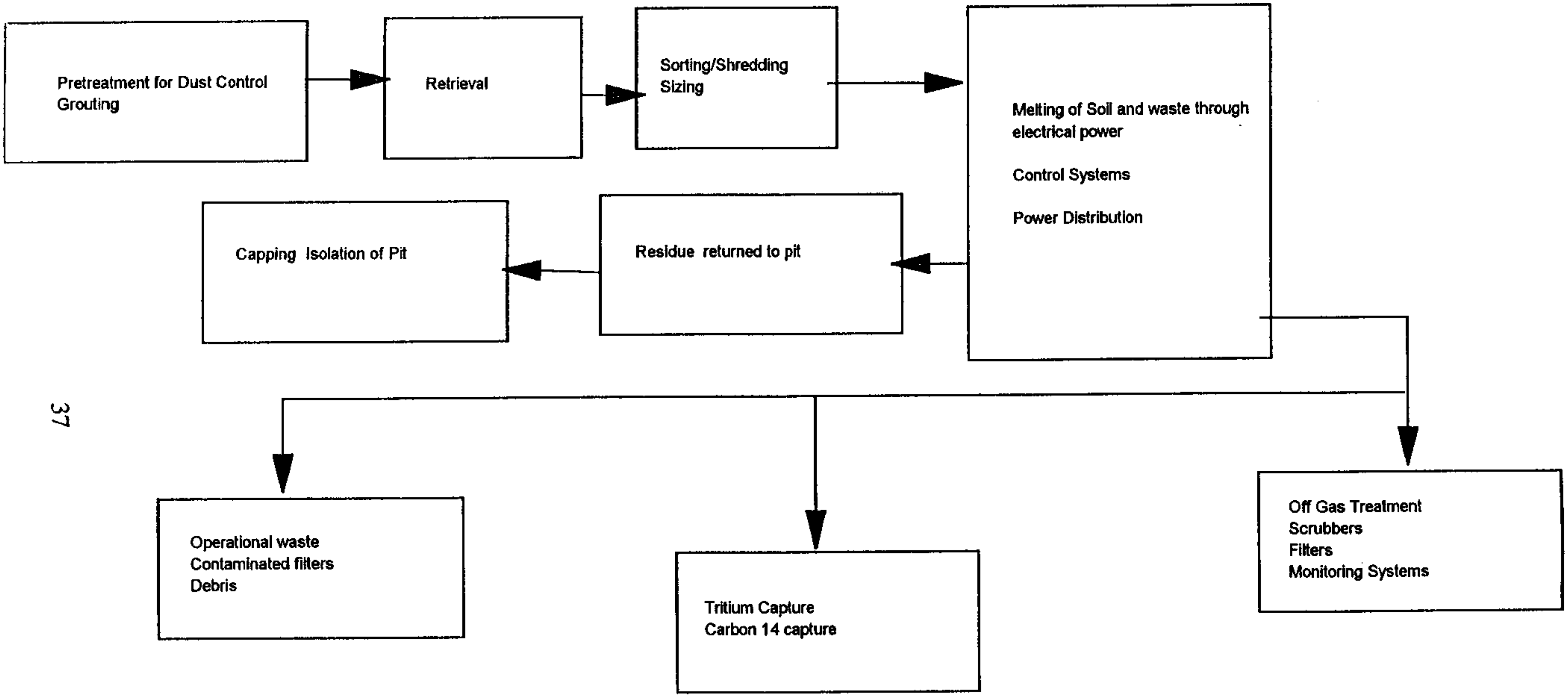


Figure 3

Moderate Treatment System

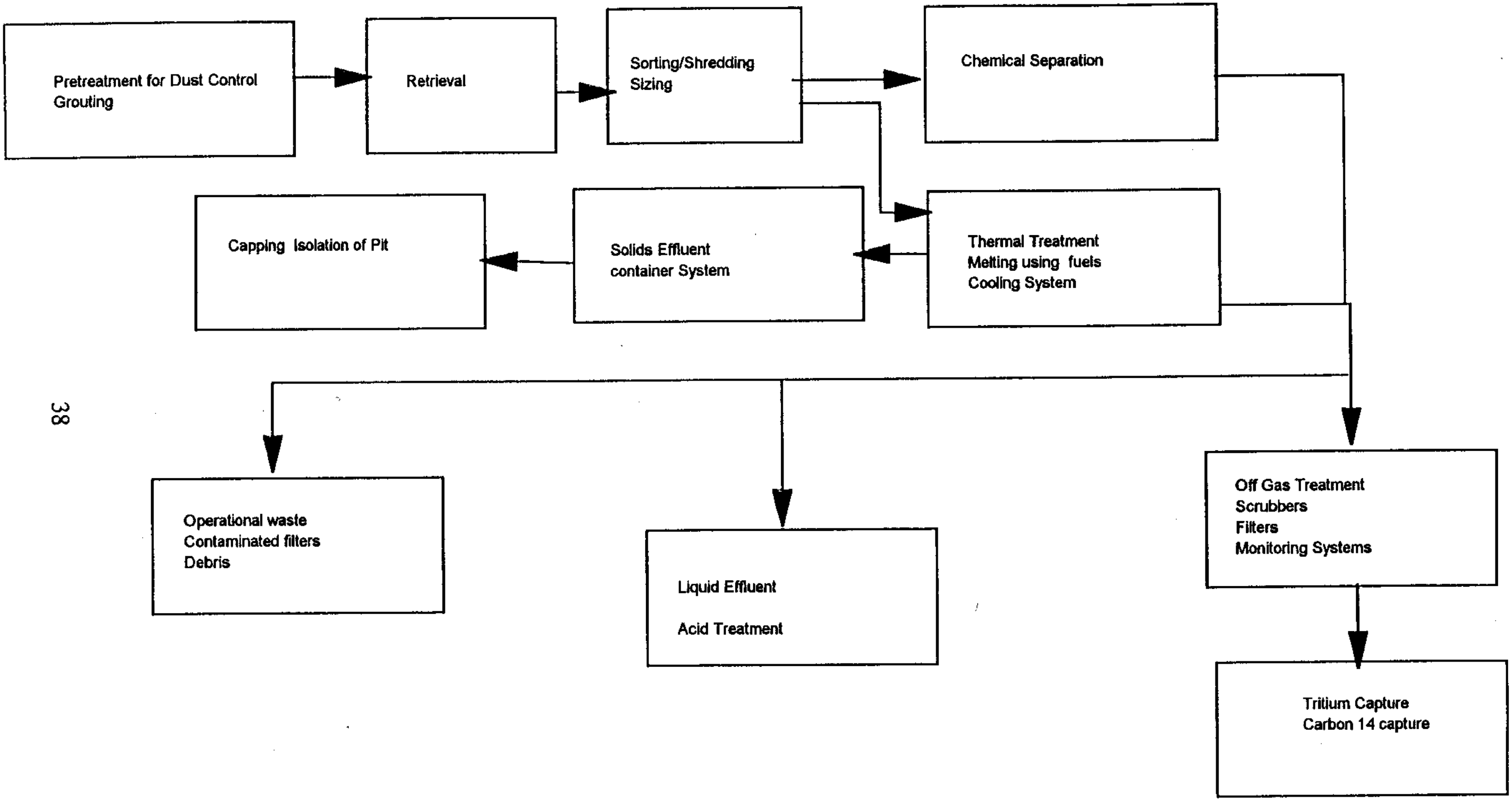
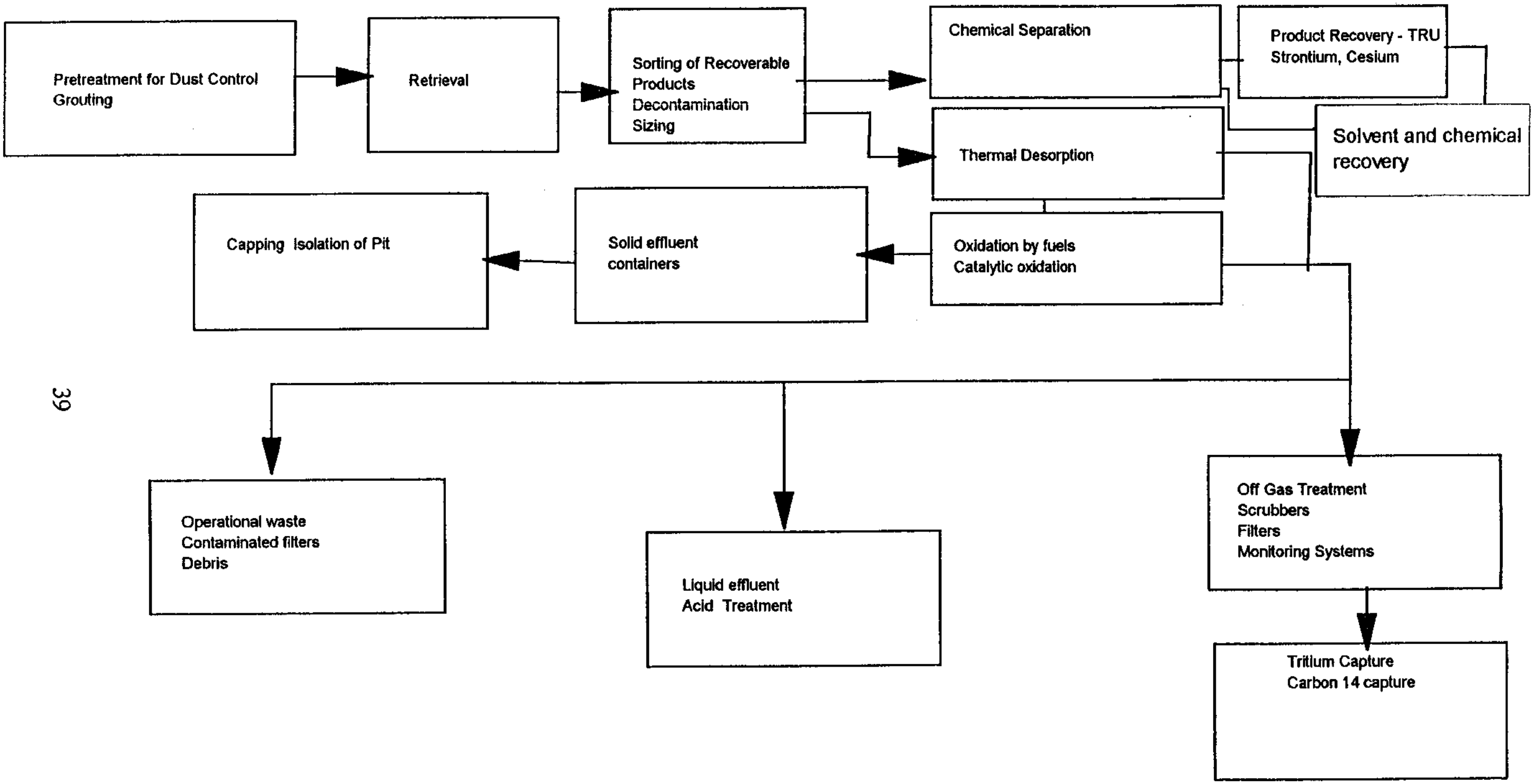


Figure 4

Extensive Treatment System and Recovery



Melting is done by electrodes placed in the soil/waste area. Offgas treatment would include quenching the offgas, scrubbing steps to remove acid gases and particulate, HEPA filters, catalytic oxidation of organics, and a carbon bed to adsorb mercury. To capture tritium and remove $^{14}CO_2$, additional steps are needed. The primary support system needed for ISV is that of electrical power generation and transmission. For the cost estimate it was assumed no excavation would be done in pretreatment to remove wastes not amenable to ISV, that the ISV electrodes would be moved both vertically and horizontally to adequately treat the site, and that the vitrified waste would be left in place.

3.3.2 Ex-Situ Vitrification Treatment System

Ex-situ vitrification consists of five subsystems: retrieval, pretreatment, melting, offgas treatment, and support systems. Pretreatment steps would prepare the soil and waste for the melter, and involve removal of large items and size reduction. It is assumed that the melter is heated electrically and hence the offgas system would be similar to that for ISV. It is also assumed that all soil and waste is vitrified. The primary support systems would be the electrical power supply and packaging of the vitrified product.

3.3.3 Moderate Treatment System

The Pit 9 remediation process is an example of a moderate treatment system. Less vitrified waste results than for ISV or ex-situ vitrification processes. Contaminants are removed from a moderate to large fraction of the soil volume such that future risks are greatly reduced from the returned soil. The system consists of six subsystems: retrieval, pretreatment, chemical separation, melting, offgas treatment and support systems. The melter was assumed to be a plasma melter, which in contrast to the first two systems, uses fuel rather than electricity for thermal energy. Pretreatment both separates soil that will be chemically cleaned from waste and highly contaminated soil that will be melted, and accomplishes the greater degree of sorting required for feed to the plasma melter. Large items, metals, and special wastes such as NaK and gas cylinders would be removed, and the waste would be shredded and then processed in the melter.

The chemical separation steps remove organics and radionuclides from the soil such that it can be returned to the ground. Soil would be washed with a solvent to remove organic contaminants and leached to remove radionuclides and hazardous metals that are COPC. Systems would be included to recover both the solvent used in soil washing and the acid used in leaching.

Because of a large volume of combustion gases from the melter due to combustion of fuel, and offgases from chemical separation steps, the offgas system will be larger than the vitrification systems. Support systems include an extensive monitoring and control system, a steam system, cooling water, decontamination of waste containers, and a wastewater treatment system. Steam is used primarily in evaporators in the acid recovery and leach systems.

3.3.4 Extensive Treatment and Product Recovery

The goal of the extensive treatment system is to minimize the amount of final TRU waste by recovering TRU elements. Lead and scrap metal would also be recovered. The treatment system includes ten subsystems. Retrieval would be similar to the other ex-situ treatment systems. The pretreatment steps would separate lead, metal, large items, irradiated fuel[a] and other special category wastes. The treatment system would make maximum use of decontamination to result in clean metal, lead and other materials that could be sold or reused at DOE laboratories. Chemical separation would not only remove organic constituents and TRU elements, but other radiological contaminants such as strontium and cesium. The concentrated TRU waste from the leach system would be further process by a TRU recovery system to recover uranium and plutonium.

Oxidation of combustible waste would be performed either by an incinerator or a catalytic oxidation unit, preceded by a thermal desorber. The system would contain a melter, but it would process mainly secondary wastes and very little soil. The other subsystems are offgas treatment, support systems similar to the moderate treatment system, and a subsystem for treatment of NaK and other pyrophoric wastes.

3.4 Process Option Examples

In order to better identify data needs for different process options, selected processes were reviewed according to the data sheets. This was not meant to be a comprehensive review of processes but was done to better identify data gaps. A more thorough review should be done and other processes reviewed during the OU 7-13/14 feasibility study.

3.4.1 Joule-heated in situ vitrification

3.4.1.1 Description

In Situ Vitrification (ISV) is a thermal treatment process that converts contaminated soil into a chemically inert and stable glass and crystalline product. This process employs Joule heating which refers to utilizing the material being heated as the resistance element in an electrical circuit. It operates by the insertion of a square array of four molybdenum and graphite electrodes into the ground into the desired treatment depth and applying an electrical potential to the electrodes to melt/vitrify the soil, debris and contaminants into a vitrified mass similar to volcanic obsidian at temperatures between 1600 to 2000 degrees centigrade. Several pretreatment technologies have been employed to render a wide array of buried waste acceptable for ISV treatment. These pretreatment options include: compaction by means of a vibratory beam, high-pressure jet grouting to inject solids into void spaces, resistance soil heating to remove VOCs and SVOCs, and selective excavation to remove unacceptable materials (i.e.; pressurized gas cylinders) followed by restaging the remaining materials for ISV processing.

[a] Waste identified as irradiated fuel is not spent fuel per the definition of DOE Order 5820.2A

ISV has been commercially available for two years. During this period it has been successfully used at two Superfund Sites and is presently treating contaminated soil at a third Superfund Site. Several design modifications have been made to the ISV system since its introduction, that have resulted in its current recognition as a preferred technology of choice for treating mixed waste. It has been selected by the British government as preferred technology for treatment at the Maralinga site (a British nuclear weapon test site) in southern Australia, to remedate 21 pits containing kilogram quantities of plutonium (22 kilograms, total), significant quantities of uranium, heavy metals, massive amounts of steel and other debris and other chemically contaminated materials.

3.4.1.2 Data Review

Technology Category:	In-Situ Treatment
Technology Names:	Joule Heated Vitrification, with pretreatment, In-Situ Vitrification
Commercial Name:	ISV, In-Situ Vitrification
Commercial Capacity:	3 to 6 tons/hr; up to 1200 tons/melt with online operating efficiency of 83% to 90%. Full-scale mixed waste capacity is still being evaluated in on-going demonstration work and is believed to be site specific based upon contaminants present, their respective concentrations, soil conditions, and pretreatment requirements such as selective sorting and container puncturing.
Demonstrated Capacity or demonstration plans:	Demonstrated capacity is same as commercial capacity shown above. Demonstration plans call for ISV Demonstrations on radioactive waste at Oak Ridge and in Australia for 1995. ISV has been identified as the "technology of choice" in a recently completed treatability study for treating buried waste at Rocky Flats, Colorado consisting of mixed waste with plutonium, uranium, many chlorinated solvents, oil, diesel, and gasoline. The demonstration at Oak Ridge National Laboratory (ORNL) is scheduled to occur in August, 1995 with three large melts of Pit 1 (30 ft wide by 115 ft long by 10+ ft deep) containing radioactive liquid waste seepage at ORNL. The contaminants of concern for this demonstration are strontium-90, Cesium-137, depleted uranium, and plutonium-239. This demonstration will be jointly performed by ORNL, Pacific Northwest Laboratory (PNL), and Geosafe Corporation, the licensed technology manufacturer.

The Maralinga site demonstration is in its second phase of a four phase project. The second phase consists of an 8-month test of an intermediate-scale ISV system (75kW) scheduled to begin in summer of 1995 on actual contaminated soils and debris at the test range.

Applicable to:	Yes	No
Contaminated soil	x	
Contaminated metal	x (up to 30-40% by weight)	
Combustible waste	x	
Cemented sludges, concrete, brick, etc.	x (up to at least 9%)	
Uncemented sludges	x	
Salts		
Nitrates	x	
Other salts	x	
Mixed waste types	x	
Drums of liquids	x (must be punctured or sufficiently degraded)	
Aqueous liquids	x (up to 75 wt% water)	
Acids	x (up to 75 wt% water)	
Organic liquids	x	
Halogenated	x	
Nonhalogenated	x	
Organophosphates	x	
Gas cylinders	x (unpressurized gas cylinders only)	
High activity waste	x (demonstration at Maralinga site, 1995)	
Pyrophoric materials	x	
Lead wastes	x	
Asbestos	x	

The following limitations must be considered and provisionally allowed for in the final ISV design process;

- o Treatment depths over 20 feet require special provisions,
- o Total organic content should be less than 10 wt% (limitation is based on off-gas cooling; could be raised to 70% with cooling redesign)
- o The media must be acceptable for joule-heated melting
- o Water recharge rates that are sufficiently high, may require a dewatering system
- o Sealed containers of liquids or gases require special provisions (pretreatment, pre-test segregation or off-gas system expansion)
- o Very large voids must be filled or collapsed.

Pretreatment requirements: (listing in addition to limitations noted above)	Yes	No
Soil conditioning;		
moisture addition (as required)	x	
graphite addition (start-up only)	x	
glass frit addition (start-up only)	x	

Level of worker exposure: ISV is one of lowest personnel exposure mixed waste treatment technologies due to minimal excavation needs and resultant personnel contact potential for contaminants being remediated. ISV can be operated remotely. A shrouded and totally enclosed hood encompasses the area being remediated. No ingress or egress is required of personnel into the enclosure during the vitrification processing.

Offgas characteristics and treatment system: The offgas treatment passes through the following sequential processing steps; quench, scrub, dewater, heat, filter, carbon adsorb, and thermal oxidizer.

Fate of volatile radionuclides? (^3H, $^{14}CO_2$, halogens...) Volatile radionuclides can be captured in the gaseous emission control system and result in a residual waste to be handled. Some process residuals (i.e.; used scrub solution, bag filters, HEPA filters, and PPE) can be disposed in subsequent melt settings to reduce the volume of these materials requiring ultimate disposal offsite. Scrubber water generated during treatment may require special handling depending upon the type and level of contaminants being treated. ^{14}C will not be captured in current offgas system design.

Fate of volatile and semivolatile metals? Same as above for subsequent handling/disposal of process residuals from volatile radionuclides.

Liquid wastes: The only liquid waste stream, identified above, is the scrubber water generated during treatment. The relative rate and composition of the scrubber water should be available from demos on radioactively contaminated sites (two are planned for 1995).

Solid wastes: No further stabilization is required, except in the case where treatment included removal of some debris. More definitive information on waste forms generated should be available from demos planned for 1995 at Maralinga, Australia, and Oak Ridge, Tennessee. Information is presently available from Parsons.

Will the following contaminants be processed into a stabilized waste form?

PCBs: The TSCA Demonstration project that concluded in November, 1994 in Spokane, Washington during which over 17,000 ppm PCBs were treated resulted in following:

- o No detectable PCBs were present in the residual vitrified product.
- o No detectable PCBs were found at the off-gas stack.
- o No measurable increase in the background PCB content was detected in the soils adjacent to the treatment zone

Note: The EPA is currently reviewing the performance report for this project.

RCRA-metals: Surpasses TCLP requirements on waste form (vitrified mass)

Reducing agents: not expected to be a problem, may cause additional metals to drop out

Ammonia: will likely be oxidized to NO_x and water; NO_x will be absorbed in offgas treatment

Sr-90:	total immobilized by ISV = 99.9999 - 99.999999
Cs-137;	total immobilized by ISV = 99.99 - 99.9999
TRU elements;	total immobilized by ISV = 99.9999 - 99.999999

Utility Requirements:

Electricity: 12.5 or 13.8 kV 3-phase required. Demand = 3.2 MW; peak = 4.0 MW
Electricity consumption: 700 to 1000kWh/ton of soil processed
Fuel: 3 MBtu/hr fuel gas support for off-gas thermal oxidizer
Water, nonpotable requirement: Site specific, to be determined.

Costs:

Demonstration/Testing: Currently being carried out by ORNL/PNL Demo.
Capital: Unknown at this time
Operating: Unknown at this time

Geosafe Corporation Literature cites costs of $370 to $420 per ton of soil treated, based upon treatment cost for hazardous waste at superfund sites treated to date by ISV. It is expected that mixed waste treatment costs will be significantly higher. Information will soon be available from the Maralinga test.

Vendors, Contacts, References:

1. VISITT 3.0 database, vitrification technology

2. *EPA Site Technology Capsule*; Geosafe Corporation In Situ Vitrification Technology, EPA 540/R-94/520a, November 1994

3. Geosafe Corporation; *In Situ Vitrification Fact Sheet*, November 1994

4. B. P. Spalding, *Treatability Study Work Plan for In Situ Vitrification of Seepage Pit 1 in Waste Area Grouping 7 at Oak Ridge National Laboratory*, Oak Ridge, Tennessee, July, 1994, DOE/OR/01-1158

5. L. E. Thompson, B. E. Campbell, J. L. McElroy, C. L. Timmerman, Geosafe Corporation, *In Situ Vitrification: Results from Three Large Scale Commercial Applications Involving Contaminated Soil and Debris and the Status of an International Application on a Mixed-TRU Buried Waste*, December, 1994

6. *Application of In Situ Vitrification to Buried Wastes*, Geosafe Corporation, April, 1995

7. Record of Telephone Communication with ORNL's B. P. Spalding, 615-574-7265 by W. J. Prendergast, June 23, 1995

8. Record of Telephone Communication with E G & G's J. McLaughlin, 303-966-6995 of Rocky Flats, Colorado by W. J. Prendergast, June 21, 1995

9. Record of Telephone Communication with INEL's R. Farnsworth, 208-526-6986 by W. J. Prendergast, June 21, 1995

10. Record of Telephone Communication with Geosafe's M. J. Haass, 509-375-0710 by W. J. Prendergast, June 20, 1995

3.4.1.3 Data Gaps

Data from the Rocky Flats treatability study and the larger scale tests at Oak Ridge and Maralinga should be obtained for evaluation of ISV in the OU 7-13/14 feasibility study. Data from these tests will establish the effectiveness and implementability for ISV at nuclear waste sites. Cost estimates from Geosafe or based on these upcoming tests should be obtained. Discussions with Geosafe are needed to better define the pretreatment system that would be required, based on SDA waste information contained in section 2, and to obtain more specific information on ISV treatment after remediation objectives are better defined. To evaluate ISV for the SDA, information on the chemical composition of SDA soil, and variation of composition with position may be needed.

3.4.2 Low temperature Joule-heated melter

3.4.2.1 Description

Low temperature Joule-heated melter technology can be applied to both in situ and ex situ treatment applications. The ex situ treatment can be batch, semi-continuous or continuous; most of the available data is based on a batch process due to the size limitations. Using joule heating, an electric current is passed through the molten material between submerged electrodes. The unique feature of the process is the addition of fluxing material to achieve vitrification at a relatively low temperature. The process itself is a joule-heated process since it uses the material itself to provide electrical resistance and thereby increase the materials temperature until it melts into a molten, glass-like state. This low temperature is possible since the fluxing material behaves like an impure substance which lowers the melting point.

Vitrification equipment which is currently available on the market may be used for the process in conjunction with the fluxing agent. The Vitriflux vendor, EM&C Engineering Associates, can supply the total process design on a site-specific basis as is normally required.

All vitrification technologies, whether they be joule-heated or incinerators using fired sources for heat input, may potentially benefit by addition of fluxing agents to lower the melt temperature and thereby reduce the temperatures in the equipment. This can permit melting to occur at temperatures that do not exceed those allowable for modern refractory materials, steel, or many metal alloys that are used for vessel shells housing the refractory liners.

3.4.2.2 Data Review

Technology Category:	In-Situ Treatment or Ex-Situ Thermal Treatment
Technology Name:	Low-Temperature Joule-Heated Melter
Commercial Name:	Vitriflux
Commercial Capacity:	Approximately 300 to 4000 lbs per hour are believed to be typical ranges, but specific feed rates for a current full scale unit being built by the vendor, EM&C Engineering Associates, was not able to be found.
Demonstrated Capacity or demonstration plans	Only one manufacturer was identified that is currently building a full-scale unit for a client per the VISITT innovative treatment technology data base as of June, 1994. That manufacturer is EM&C Engineering Associates of Cosa Mesa, California. The capacity of the process was not published, but it was stated that two additional units were being designed at that time. It is anticipated that the unit being built in 1994 is now operational and that this data will become available.

Applicable to:	Yes	No
Contaminated soil	x	
Contaminated metal	x	
Combustible waste	x	
Cemented sludges, concrete, brick, etc.	x	
Uncemented sludges	x	
Salts		
Nitrates	x	
Other salts	x	
Mixed waste types	x	
Drums of liquids	x (must be punctured first)	
Aqueous liquids		x
Acids		x
Organic liquids	x	
Halogenated	x	
Nonhalogenated	x	
Organophosphates	x	
Gas cylinders	x (unpressurized gas cylinders only)	
High activity waste	x (potentially)	
Pyrophoric materials		x
Lead wastes	x	
Asbestos	x	

Restrictions on feed form: The following limitations must be considered and provisionally allowed for, for in-situ application:

- o Treatment depths over 20 feet require special provisions,
- o Total Organic content should be less than 10 wt%
- o The media must be acceptable for joule heated melting
- o Water recharge rates that are sufficiently high, may require a dewatering system
- o Sealed containers of liquids or gases require special provisions
- o Very large voids must be filled or collapsed.

Pretreatment requirements: (in addition to limitations noted above)	Yes	No
Soil conditioning;		
moisture addition (as required)	x	
graphite addition (start-up only)	x	
glass frit addition (start-up only)	x	

Retrieval (for ex-situ application):

Waste removal from containers	x (probable)
Sorting (if yes, describe)	x (pressurized gas cylinders must be removed prior to vitrification)
Sizing	x (unknown sizing requirements)

Level of worker exposure: Probably very low for in situ; actual demo results needed.

Offgas characteristics and treatment system: No information is available. It may require some additional offgas treatment requirement if the fluxing agent(s) enter into any chemical reactions with the waste.

Fate of volatile radionuclides? Unknown. Demonstration data is needed.

Fate of volatile and semivolatile metals? Unknown. Demonstration data is needed.

Liquid wastes: Unknown. Demonstration data is needed.

Solid wastes: No further stabilization is believed to be required.

Will the following contaminants be processed into a stabilized waste form?

PCBs: The system vendor claims that PCBs will be handled/treated effectively, but no data was provided to support that claim.

RCRA-metals: No data provided but it should be similar to the vitrification process it is used with for passing TCLP requirements.

Reducing agents: unknown at this time

Ammonia: unknown at this time

Sr-90: unknown at this time.
Cs-137: unknown at this time.
TRU elements: unknown at this time.

Utility Requirements:

Electricity: 12.5 or 13.8 kV 3-phase required. Demand = 3.2 MW; peak = 4.0 MW

Electricity consumption: 700 to 1000kWh/ton of soil processed

Fuel: Unknown at this time.
Water, nonpotable requirement: Site specific, to be determined.

Costs:

Demonstration and Testing: Unknown at this time.
Capital: Unknown at this time
Operating: Unknown at this time

EM&C Engineering Associates cites $40 to $100 per ton of contaminated soil, but it is believed that the actual cost for treatment of mixed waste streams will be considerably higher, especially if the process is carried out ex situ.

Vendors, Contacts, References:

1. VISITT 3.0 database, vitrification technology, Environmental Protection Agency, June, 1994.

2. Telephone Communication (714-957-6429) with Mr. Mahamed Elgafi, President of EM&C Engineering Associates, July 5, 1995.

3.4.2.3 Data Gaps

From this preliminary data review, the following data gaps were identified for this process:

1. full-scale capacity
2. feed sizing requirements for ex-situ application
3. demonstration results to better evaluate worker exposure, secondary waste rates and types, and the stability of vitrified waste for the wide range of types of SDA buried waste
4. ability to treat wastes containing reducing agents, ammonia, RCRA-hazardous metals, Sr-90, Cs-137, and transuranics
5. offgas system performance
6. utilities requirements
7. costs.

3.4.3 Plasma arc/torch melter

3.4.3.1 Description

The Plasma Arc Centrifugal Treatment System (PACT) uses electric energy from an arc, which operates between a plasma torch and a rotating tub, to detoxify the material feed. The tub rotates on a vertical axis inside a sealed chamber. The organic substances vaporize and are burned (at 2000°F), partly in the reaction tub and partly in a downstream secondary combustion chamber. Virtually all the inorganics become part of the glassy melt in the tub (in excess of

3,000°F) held in place by centrifugal force. At suitable intervals, rotation is slowed and part of the melt is tapped through the bottom of the tub into a mold. The cooled, solidified residue can be either entirely glassy or partly crystalline; the residue will pass Toxicity Characteristics Leaching Procedure (TCLP) tests in either case. The partly burned gases from the chamber also exit through the bottom of the tub and are directed to the secondary combustion chamber, and from there to a gas cleanup system. The advantage of the PACT process is that virtually all of the material fed is converted into either a non-leachable solid which meets all the criteria for delisting or into a gas suitable for discharge into the atmosphere. Much of the cleanup system residues can either be recycled or discarded, leaving a net residue that can be less than 2 percent of the material feed.

3.4.3.2 Data Review

Technology Category:	Thermal Treatment
Technology Names:	Plasma arc/torch melter
Commercial Name:	Plasma Arc Centrifugal Treatment (PACT) System
Commercial Capacity:	2000 to 4000 lbs per hour.
Demonstrated Capacity or demonstration plans	A Proof of Process (POP test) utilizing the PACT system has been completed for the planned remediation of Pit 9 located in the Subsurface Disposal Area (SDA) at the Radioactive Waste Management Complex (RWMC) at the INEL. The PACT system as designed and modified to meet the needs of the Request for Proposal (RFP) passed the POP test criteria. Currently, a full scale processing system for Pit 9 is in the final design phase. As called for in the RFP, the full scale processing system will perform a Limited Production Test (LPT) to demonstrate the full scale system on a limited quantity of Pit 9 waste forms. This LPT is planned to occur in late 1996. Much was learned during the POP test and resulted in design modifications of several parts of the Plasma Arc/Torch system. The LPT will demonstrate the total integrated processing system and thereby prove it's overall viability/capability to remediate Pit 9. The results of the LPT will be very useful information in assessing this technology for the subsequent remediation of the SDA and will be very important assistance in the determination of how well this technology can meet the treatment/remediation needs for OU 7-13/14. As of June, 1994 there were four plasma arc furnace units employing the PACT process operating in a demonstration mode of operation; a 500 kW unit at Butte, Montana, 150 kW and a 200 kW units in Ukiah, California, and a 1200 kW unit in Muttenz, Switzerland. All of these units are referred to as full scale units

by the manufacturer, Retech, Inc., but admittedly the 150 and 200 kW units are almost an order of magnitude smaller than the 1200 kW unit, so they could more easily be thought of as pilot scale in size.

Applicable to:	Yes	No
Contaminated soil	x	
Contaminated metal	x	
Combustible waste	x	
Cemented sludges, concrete, brick, etc.	x	
Uncemented sludges	x	
Salts		
Nitrates	x	
Other salts	x	
Mixed waste types	x	
Drums of liquids	x (may require premixing with solids)	
Aqueous liquids	x (may require premixing with solids)	
Acids	x (may require premixing with solids)	
Organic liquids	x (may require premixing with solids)	
Halogenated	x	
Nonhalogenated	x	
Organophosphates	x	
Gas cylinders	x (unpressurized gas cylinders only)	
High activity waste	x (must be demonstrated)	
Pyrophoric materials	x (concentration dependent)	
Lead wastes	x	
Asbestos	x	

Restrictions on feed form:

- o Loose solids not greater than 6 to 8 cubic inches
- o Drum waste may be fed, but provisionally the feed system must facilitate size of containers. The material feed system design can facilitate this.
- o Although the feedstock may be liquid, slurry, or loose solid, premixing must be considered to provide a homogeneous feedstock with a similar consistency and heating value to minimize adjustments to the manual firing mode settings and insure around-the-clock operation.
- o Sealed containers of liquids or gases require special provisions

o Very large containers and miscellaneous debris requires prior segregation to insure that only those items requiring slagging are introduced into the furnace

Pretreatment requirements: (in addition to limitations noted above)	<u>Yes</u>	<u>No</u>
Soil conditioning; addition of agent for electrical conductivity/ viscosity control	x	
Retrieval:		
Waste removal from some containers	x (probable need for contents verification)	
Sorting (if yes, describe)	x (pressurized gas cylinders must be removed prior to vitrification)	
Sizing (if yes, to what size particle)	x (less than 6 to 8 inches cube size)	
Other (larger items for decon only)	x (i.e; reactor shell segments, etc.)	
Removal of all contaminated soil/debris	x (total excavation required)	

Level of worker exposure: There is some potential for exposure. Some designs call for completely enclosed systems for both the excavation of the Pit and the actual remediation operation and associated monitoring of adjacent/surrounding areas for contaminant containment and control. The process could likely be operated remotely, but actual demonstration results will determine system reliability and confirm whether both operation and maintenance can be carried out remotely and/or with safety to minimize personnel exposure to all contamination.

Offgas characteristics and treatment system: A gas cleanup system will be employed for acid gas and dust removal with full remote instrument control.

Fate of volatile radionuclides: Mixed waste treatment demonstration (LPT) is required for this determination. Surrogate (cerium) used during POP test showed acceptable accountability. Approximately 98 percent was captured in the slag and the remaining 2 percent was in the scrubber system. There was no surrogate cerium found in the off-gas solids.

Fate of volatile and semivolatile metals: Actual operation data is needed for this determination from the Limited Production Test. The POP test was positive and showed that LDR limits were easily met in slag pour test results for arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver.

Liquid wastes: Carbon Tetrachloride and 1,1,1-trichloroethane were evaluated as additives for the POP test treatment. A good mass balance for chlorine was not achieved due to several reasons, but the judgement was that the liquid waste additives were effectively treated by the system.

Further stabilization required? In the POP test results, an acceptable waste form of slag met or exceeded LDR criteria and the INEL TRU Waste Acceptance Criteria (INEL TRU WAC). Some additional recycle of metal particulates will probably be required as 2 percent of the surrogate, cerium was found in the scrubber system. The LPT results will verify final waste forms and justification for recycling of metal particulates.

Will the following contaminants be processed into a stabilized waste form?

PCBs: Not evaluated in the POP test. There is no available data.
RCRA-metals: Passed LDR requirements for POP test.
Reducing agents (hydrazine): Not evaluated in the POP test, expected to be oxidized to NO_x and water.
Ammonia: Not evaluated in the POP test; expected to be oxidized to NO_x and water; offgas treatment would be expected to contain an NO_x reactor.
Sr-90: Not evaluated in the POP test.
Cs-137: Not evaluated in the POP test.
TRU elements: A good correlation was obtained between plutonium and the surrogate cerium. The INEL TRU WAC criteria were met by the POP test (INEL TRU WAC criteria include criteria of pH, detonation potential, VOC concentration, particulate, chemical compatability, and gas generation).

Utility Requirements:

Electricity: 12.5 or 13.8 kV 3-phase required. Demand = 3.2 MW; peak = 4.0 MW
Electricity consumption: 700 to 1000 kWh/ton of soil processed. (Estimated)
Fuel (type & rate): Unknown at this time.
Water, nonpotable requirement: Site specific, to be determined.

Costs: The estimated cost for treatment is $600 to $1200 per ton (Retech estimate). It is expected that this cost data is based upon hazardous waste treatment without the mixed waste additional operating expenses for remote operation and degree of testing/monitoring that will be needed for PIT-9 and OU 7-13/14.

Vendor contacts, References:

1. VISITT 3.0 database, vitrification technology, Environmental Protection Agency, June, 1994.

2. *Standard Handbook of Hazardous Waste Treatment and Disposal*; Harry M. Freeman, Editor in Chief, 1988.

3. *Mixed and Low-Level Waste Treatment Facility Project, Vol. 3*, INEL, September, 1992.

4. *PIT-9 Proof-of-Process Test; Comprehensive Evaluation Report*, EG&G Idaho, March, 1994.

5. Telephone communication with Brent Burton (208-526-8695) requesting pertinent information on the size and through-put feed rate of the LPT for reference.

6. Record of Decision for Pit 9, *Declaration for Pit 9 at the Radioactive Waste Management Complex Subsurface Disposal Area at the Idaho National Engineering Laboratory*, October, 1993.

7. R. L. Gillins, L. M. DeWitt, A. L. Wollerman, *Mixed Waste Integrated Program Interim Evaluation Report on Thermal Treatment Technologies*, DOE/MWIP--2, February, 1993.

3.4.3.3 Data Gaps

Data from the LPT and other demonstration tests are needed to evaluate reliability, feasibility of remote operation, secondary waste quantities and compositions, behavior of non-TRU radionuclides such as Sr-90 and Cs-137, behavior of volatile and semivolatile radionuclides, and to verify the nonleachability of final waste forms. Cost estimates are also needed.

Because the plasma furnace proposed for Pit 9 remediation is still in the developmental stage, uncertainties exist regarding its performance for the wide range of wastes present in the SDA and for a long-term remediation. Data from the limited production test will not be available until late 1996. In addition to the data gaps identified above in the general data review, other data needed includes details of the feed handling system to evaluate its ability to provide a constant, homogenous feed, and the ability to adequately control the slag handling system, including during abnormal shutdowns. According to the DOE mixed waste integrated program evaluation of thermal treatment technologies (Reference 7 above), performed in 1993, development needs of the plasma arc furnace are "optimization of slag chemistry for metals stabilization, evaluation of variation in slag chemistry resulting from variations in the input stream, reintroduction of condensed volatile metals into the slag phase, electrode life studies, destruction and removal efficiency of hazardous organics. safety assessments for heterogeneous waste processing, and determination of radionuclide partitioning in slag/metal phases".

3.4.4 Cyclone furnace vitrification

3.4.4.1 Description

The cyclone furnace vitrification process consists of an above ground, ex-situ process for the oxidation and vitrification of soils, sludges, ashes, and sediments that have organic, inorganic, heavy metals, and/or radionuclide contaminants. Cyclone furnaces are cylindrically shaped, refractory lined steel shells that can have a vertical or horizontal orientation. The primary feature of cyclone furnaces is cyclonic flow action of the combustion gases in the cylindrical main chamber, to promote gas-phase mixing and remove inert ash by impaction on the chamber wall.

In the B & W Cyclone Vitrification process, the system also has the ability to oxidize and vitrify materials introduced as slurries, thus providing the capability of mixing waste fuels, along with the waste to be oxidized/vitrified. The cyclone furnace is designed to achieve very high heat release rates, temperatures, and turbulence. Particulate matter from the soil stream is retained along the walls of the furnace by the swirling action of the combustion air and is incorporated into the molten slag. The slag, which has a temperature of 2,400°F, exits the cyclone furnace from a tap at the cyclone throat and drops into a water-filled tank where the material is quenched. A small portion of the soil exits as flyash with the flue gas from the furnace and is collected in a baghouse. A heat exchanger cools stack gases to approximately 200°F before they enter the baghouse. Natural gas and preheated combustion air (heated to 820°F) enter tangentially into the cyclone burner. Soil for processing enters along with the gas and air through a soil injector.

In the Vortec Corporation's Combustion and Melting System (CMS), the primary thermal processing components consist of an in-flight suspension preheater and a cyclone melter. Contaminated wastes (in slurry or dry form) are continuously introduced into the suspension preheater, where heating and oxidation of the waste materials are initiated. The suspension preheater is a fossil fuel-fired counter-rotating vortex (CRV) combustor designed to oxidize any organics in the waste and provide suspension preheating of the inorganic materials. The average temperature of the materials leaving the CRV combustion chamber is typically between 2,200 and 2,700°F. The preheated solid materials exiting the CRV combustor enter the cyclone melter, where they are separated to the melter walls to form a molten glass layer. The vitrified glass product and the exhaust gases exit the cyclone melter through a tangential exit channel and enter a glass and gas separation assembly. The exhaust gases then enter an air preheater for waste heat recovery and are subsequently delivered to an air pollution control subsystem for particulate and acid gas cleanup. The molten glass product exits the glass/gas separation chamber through a slag tap and is delivered to a water quench assembly for subsequent disposal.

3.4.4.2 Data Review

Technology Category:	Thermal Treatment
Technology Names:	Cyclone Furnace Vitrification
Commercial Name:	Combustion & Melting System (CMS); Cyclone Vitrification
Commercial Capacity:	400 to 33,000 lbs per hour.
Demonstrated Capacity or demonstration plans:	The demonstrations carried out to date by both manufacturers include the following: a munitions manufacturing waste treatment carried out for Oak Ridge National Laboratory that consisted of Toxic Substances Control Act (TSCA) incinerator ash contaminated with arsenic, barium, cadmium, chromium, lead, cesium, and cerium and which was completed in December, 1993. The EPA SITE Emerging Technology Program was carried out on both the B&W Cyclone Furnace and the Vortec CMS technologies in which an EPA synthetic soil matrix (SSM) was the feed material. In this soil matrix, a number of actual contaminants and surrogates were implanted in the soil as spiked quantities. Both technologies readily passed the TCLP tests for the heavy metals contained in the product slag. In the SITE demonstration for B & W's cyclone furnace, heavy metals, semivolatile organics, and simulated radionuclides were added as spiked quantities in the EPA synthetic soil matrix. The destruction and removal efficiency (DRE) for the semivolatiles was greater than 99.99 percent. There was a 28 percent reduction in volume between the feed and slag product, and about 95 percent of the non-combustible portion of the SSM was incorporated within the slag. Vortec Corp. has completed 80 pilot scale studies on wastes from different sources or sites and 20 bench scale studies. Vortec's CMS is considered to be commercialized and three units are in the design/planning stages for full scale construction. B & W's cyclone vitrification process is still in the pilot scale development mode.

Applicable to:	Yes	No
Contaminated soil	x	
Contaminated metal	x	
Combustible waste	x	
Cemented sludges, concrete, brick, etc.	x	
Uncemented sludges	x	
Salts		
Nitrates	x (may require special refractory)	
Other salts	x (may require special refractory to prevent spalling effects)	
Mixed waste types	x	
Drums of liquids	x (may require removal from drum first and drum-shredding before the drum is fed into the furnace)	
Aqueous liquids	x (may require premixing with solids to provide good feed homogeneity)	
Acids	x (may require premixing with solids for best feed homogeneity)	
Organic liquids	x (may require premixing with solids for best feed homogeneity)	
Halogenated	x	
Nonhalogenated	x	
Organophosphates	x	
Gas cylinders	x (unpressurized gas cylinders only)	
High activity waste	x (must be demonstrated)	
Pyrophoric materials	x (concentration dependent)	
Lead wastes	x	
Asbestos	x	

Restrictions on feed form (particle size, container shape, waste phase...): (describe)

- Loose solids not greater than 3/8 inch in diameter are necessary for good mixing, uniform melting, and related feed pretreatment to achieve homogeneity. This may require that size reduction of soil and debris be accomplished by passing it through grinders or delumpers like the type manufactured by Franklin Miller. Shredding of drums to strips of steel of an appropriate size for feeding into a cyclone furnace may be an alternative to decontaminating them.

- Drum waste may be fed, but provisionally the feed system must facilitate size of containers. The material feed system design can facilitate this as described above.

- o Although the feedstock may be liquid, slurry, or loose solid, premixing must be considered to provide a homogeneous feedstock with a similar consistency and heating value to minimize adjustments to the manual firing mode settings and insure around-the-clock operation.

- o Sealed containers of liquids or gases require special provisions.

- o Very large containers and miscellaneous debris require prior segregation to insure that only those items requiring slagging are introduced into the furnace.

Pretreatment requirements: (in addition to limitations noted above)	Yes	No
Retrieval:		
Waste removal from some containers	x (probable)	
Sorting (if yes, describe)	x (pressurized gas cylinders must be removed prior to vitrification)	
Sizing (if yes, to what size particle)	x (3/8 inch or less solids)	
Other (larger items for decon only)	x	
Removal of all contaminated soil/debris	x (total excavation required)	

Level of worker exposure: Some potential exists that exposure are dependent to a large extent on the amount of non-routine maintenance that will be required. The process can be operated remotely, but actual demonstration results are required to determine system reliability and insure that both operation and maintenance can be carried out remotely.

Offgas characteristics treatment system: A gas cleanup system will be employed for acid gas and dust and removal with full remote instrument control.

Fate of volatile radionuclides: A mixed waste treatment demonstration is required for this determination. Surrogates used during the B & W SITE test (strontium, bismuth, and zirconium) were immobilized within the slag according to American Nuclear Society Method 16.1.

Fate of volatile and semivolatile metals? Actual demonstration data is needed for this determination. The SITE test was positive and showed that there was good accountability for Cd, Cr, and Pb in the partitioning between the slag and baghouse waste. The baghouse solids will require recycling or disposal as a hazardous waste, but the quantity of solids in the baghouse was relatively small.

Liquid wastes: Completely oxidized in POP test. A greater than 99.99 percent DRE was measured for semivolatile organics added to feed.

Further stabilization required? An acceptable waste form that passed the TCLP test was evident from the SITE test results. Some additional recycle of metal particulates will probably be required.

Will the following contaminants be processed into a stabilized waste form?

PCBs: Not evaluated.
RCRA-metals: Passed TCLP requirements for SITE test.
Reducing agents such as hydrazine: Not evaluated.
Ammonia: Not evaluated.
Sr-90: SITE test results showed a very high recovery in the slag.
Cs-137: Not evaluated.
TRU elements: Simulated radionuclides were immobilized in the slag.

Utility Requirements:

Electricity: Not known; Site specific.
Water; nonpotable requirement; Site specific, to be determined.

Costs:

The estimated cost for treatment is $40 to $100 per ton. (Vortec estimate). It is expected that this cost data is based upon hazardous waste treatment without the mixed waste additional operating expenses for remote operation and degree of testing/monitoring that will be needed for OU 7-13/14.

Vendor contacts, References:

1. VISITT 3.0 database, vitrification technology, Environmental Protection Agency, June, 1994.

2. *Babcock & Wilcox Cyclone Furnace Vitrification Technology, Application Analysis Report*, SITE Program, EPA/540/AR-92/017

3. "Cyclone Furnace Destroys Organics, Immobilizes Heavy Metals, Radionuclides," *Hazmat World*, August, 1992

4. *Standard Handbook of Hazardous Waste Treatment and Disposal*, Harry M. Freeman, Editor in Chief, 1988.

5. *Mixed and Low-Level Waste Treatment Facility Project, Vol. 3*, INEL, September, 1992.

3.4.4.3 Data Gaps

Demonstration results are required to determine system reliability and insure that both operation and maintenance can be carried out remotely. Test data are also needed determine the fate of volatile and semivolatile metals, and rates and types of secondary wastes. Additional information is needed on the destruction of PCBs, reducing agents, and ammonia, and the fate of cesium and other radionuclides. Utility and cost data are needed.

3.4.5 Rotary Kiln

3.4.5.1 Description

The Rotary Kiln is a cylindrical refractory-lined shell mounted on a slight (1 to 5-degree) incline. Waste is fed in the high end and ash from combustion is discharged from the low and opposite end of the slowly rotating vessel. There are seals at both ends of the kiln to provide for fixed entry feed and support fuel and fixed exit product ash and offgas. The rotary kiln is in many ways an almost ideal incinerator because it provides a great deal of waste processing versatility. For example, it effectively handles a wide range of feed types of waste, has a simplistic and robust design, and yields a good combination of residence time and temperature for complete combustion and thermal destruction of essentially all organic and inorganic waste constituents. Rotary kilns provide for the mixing and conveyance of solids for improved heat transfer and a good gas/solid separation space as the waste being treated tumbles down the length of the kiln. Design criteria for solids residence time are the angle of incline, the rotation speed, and internal baffling at the solids discharge end to encourage ash and solid holdup.

Rotary Kilns normally require a secondary combustion chamber to ensure complete incineration/combustion of the hazardous constituents. Devolatilization and pyrolysis of the combustible waste typically occurs in the kiln section under starved air input at temperatures from 1100 to 1500°F, but may be operated for complete oxidation with excess air and temperatures as high as 2500°F. Gas phase incineration is completed in the secondary combustion section at temperatures ranging from 1800 to 3000°F. An extensive offgas system is generally required to control the high volume of emissions. Due to its robust design and shape, the rotary kiln minimizes the amount of hand sorting of waste fed and the degree of feed pretreatment required. It can feed drums of waste without the need to shred the drums into small pieces prior to feeding as is required in almost all other types of thermal treatment processes.

3.4.5.2 Data Review

Technology Category:	Thermal Treatment
Technology Name:	Rotary Kiln

Commercial Name: Rotary Kiln Incineration

Commercial Capacity: 300 to 6000 lbs/hr of solid waste.

Demonstrated Capacity or demonstration plans

Rotary kilns are accepted technology for the treatment of hazardous (nonnuclear) waste. There are approximately 75 commercial facilities using this technology. Demonstration rotary kiln units have been built for mixed waste trials at several DOE facilities and another one was pending NEPA approval in 1991 before construction started.

In 1991, there were three rotary kilns located for use/evaluation at DOE facilities: a 30 million Btu/hr unit for 3000 lb/hr of Low-Level mixed waste at Oak Ridge National Lab, an 8.5 million Btu/hr unit for 600 lb/hr of TRU solid waste at the Idaho National Engineering Lab (PREPP unit), and a 1 million Btu/hr unit for 90 lb/hr of waste for Pu recovery at Rocky Flats. The kiln located at the INEL was never operated with radioactive waste due primarily to problems associated with the upgrade of the facility to meet new DOE requirements. An 18 million Btu/hr unit planned for use at the Savannah River DOE was awaiting air permitting and NEPA approval before construction could begin.

More recently, in July 1993, the rotary kiln was identified as one of the top four treatment technologies in a report by DOE (DOE/MWIP-2) for the treatment of mixed waste at DOE storage facilities at all the DOE National Laboratories. The report was a work effort involving input from all the National Laboratories, the DOE, the EPA, and other entities.

Applicable to:	Yes	No
Contaminated soil	x	
Contaminated metal	x	
Combustible waste	x	
Cemented sludges, concrete, brick, etc.	x	
Uncemented sludges	x	
Salts		
Nitrates	x (may require special refractory)	
Other salts	x (may require special refractory to prevent spalling effects)	
Mixed waste types	x	
Drums of liquids	x (premixing with solids to provide good feed homogeneity)	

Acids	x (may require premixing with solids for best feed homogeneity)
Organic liquids	x (2nd combustion chamber designed basis critical to ensure complete destruction)
Halogenated	x
Nonhalogenated	x
Organophosphates	x
Gas cylinders	x (unpressurized gas cylinders only)
High activity waste	x (must be demonstrated)
Pyrophoric materials	x (concentration dependent)
Lead wastes	x
Asbestos	x

Restrictions on feed form:

- o Drum waste may be fed, but provisionally the feed system must facilitate size of containers. The material feed system design can facilitate this as described above. The refractory-type, kiln temperature, and discharge weir design will permit drum feeding into the rotary kiln. The Dow Chemical Rotary Kiln in Midland, Michigan handles drums, hazardous liquids, sludges, and slurries, employs 98% alumina refractory and uses a design temperature in the primary kiln of 2800°F.

- o Sealed containers of liquids or gases may require special provisions

- o Very large debris items require prior segregation to insure that only those items requiring slagging are introduced into the furnace. (i.e; selective removal of very large items for decontamination is necessary.)

Pretreatment requirements: (listing in addition to limitations noted above)	Yes	No
Retrieval:		
Waste removal from some containers	x (probable, especially if sealed containers)	
Sorting	x (pressurized gas cylinders must be removed prior to incineration)	
Sizing	x (dependent upon feed design and design temperatures, if ashing only, typically 1/16 to 1/8 inch dia. particles; if ashing/slagging; drums can be charged and larger particles)	
Other (larger items for decon only)	x	

Retrieval of all contaminated soil/debris x (total excavation required)

Level of worker exposure: Some potential exists that is dependent to a large extent on the amount of non-routine maintenance that will be required. Rotary kilns are robust in their design and typically have much lower maintenance requirements than other thermal treatment incinerators of similar high temperature designs.

The rotary kiln can be operated remotely, but actual demonstration results are required to determine system reliability and insure that both operation and maintenance can be carried out remotely.

Offgas characteristics and treatment system: A gas cleanup system will be employed for acid gas and dust removal with full remote instrument control.

Fate of volatile radionuclides: Offgas system would need to be designed to capture volatile radionuclides.

Fate of volatile and semivolatile metals: Data is available for many metals (see Reference 9).

Liquid wastes: Completely oxidized/thermally-destroyed. A greater than 99.99 percent DRE is basis for design. (design basis for residence time and temperature achieved)

Further stabilization required? No. An acceptable waste form that will pass the TCLP test is evident from prior demonstration results. Some recycle of metal particulates may be required.

Will the following contaminants be processed into a stabilized waste form?

PCBs:	Complete destruction.
RCRA-metals:	Passes TCLP requirements.
Reducing agents (hydrazine):	Not evaluated, but likely oxidized to NO_x.
Ammonia:	Not evaluated, but likely oxidized to NO_x.
Sr-90:	Unknown.
Cs-137:	Unknown.
TRU elements;	Unknown.

Utility Requirements:

Support Fuel Requirements specific to heating value of waste treated.
Electrical usage is design specific for application.

Costs:

The estimated cost for treatment is $150 to $750 per ton.
($2,500 to $10,000 per daily ton of feed capacity)

Vendor contacts, References:

1. *Mixed Waste Integrated Program Interim Evaluation Report on Thermal Treatment Technologies*, DOE/MWIP-2, 1993

2. *Integrated Thermal Treatment System Study, Phase 2 Results*, LITCO-MS-11211, Third Draft, 1995

3. *Mixed and Low-Level Waste Treatment Facility Project, Volume 3*, EGG-WMO-10244, 1992

4. *Standard Handbook of Hazardous Waste Treatment and Disposal*, Harry M. Freeman, Editor in Chief, USEPA, 1988.

5. *Handbook of Incineration Systems*, Calvin R. Bruner, P.E., D.E.E., Incinerator Consultants, Inc.,1991.

6. *Rotary Kiln Incinerators: The Right Regime*, Roy W. Wood, et al, ASME Research Committee on Industrial and Municipal Waste, Mechanical Engineering, Sept. 1989

7. *Thermal Treatment Technologies for Hazardous Waste Remediation*, Nancy P. Johnson, et al, Pollution Engineering Magazine, October, 1989

8. *Incineration of Industrial Hazardous Wastes and Sludges*, Marshall Sittig, Pollution Technology Review; No. 63, Rotary Kiln Incinerators, pp. 293-320, 1979.

9. "Incineration of Hazardous Waste: A Critical Review Update," C. R. Dempsey, E. T. Oppelt, *Air & Waste 43*, January, 1993, pp. 25-73.

3.4.5.3 Data Gaps

Much of the same data are needed for rotary kiln incinerators as for other thermal treatment technologies, including utilities, costs, reliability, and amenability to remote operation and maintenance. Because of the widespread use of rotary kiln incineration for hazardous waste, much of this information should be available, or available information should provide a good basis for estimates. Less data is available for rotary kilns processing radioactive waste, and thus the main data gap may be to determine the stability of ash contaminated with various radionuclides of interest. Also, based on the experience of PREPP, data is needed on containment of radioactivity during operations and maintenance.

3.4.6 Thermal Desorption

3.4.6.1 Description

There are a large number of very similar technologies that all fall under the general heading of "thermal desorption". All of these technologies are designed to remove volatile organic contaminants from contaminated soil in an ex situ fashion at temperatures that are well below typical incineration temperatures. The mechanisms for accomplishing the heat input into the contaminated waste or soil vary considerably between technologies and typically the thermal desorption systems offered by vendors all employ a several steps for removing the volatile organic compounds and subsequently disposing of these compounds. As of June, 1994, there were thirty-four vendors of thermal desorption systems listed in the VISITT data base by EPA; twenty-eight full-scale demonstrated systems and six pilot-scale systems. The most important consideration of the value of thermal desorption as it applies to mixed waste treatment is that the VOCs can preferentially be removed separately by volatilization from all metals that have much lower vapor pressures. Therefore, thermal desorption may be used effectively to separate VOCs from heavy metals and radioactive metals.

Brief descriptions follow for the five main types of thermal desorption technologies that are currently offered:

1. Low Temperature Thermal Treatment marketed by Roy F. Weston is a continuous operation that utilizes a hollow flight screw conveyor to indirectly heat the soil to approximately 560°F by means of a circulating heating media (typically steam or hot oil) that passes through the hollow flights of the thermal processor. The offgas containing the volatiles passes through a pollution control system including a baghouse, two condensers in series orientation, and a carbon adsorption system.

2. Low Temperature Thermal Aeration marketed by Canonie Environmental Services Corporation is a continuous process in which the soil is heated to temperatures between 300 and 800°F in a rotary drum dryer by a countercurrent hot air stream which volatilizes the organics from the soil to the air stream. The offgas is treated using either carbon adsorption beds or an afterburner.

3. Tandem SRU marketed by Thermotech Systems Corporation is a continuous process in which the soil is heated to temperatures between 600 and 1400°F, depending on the model selected/required. It operates in an indirect fired mode with heat recovery where the offgas is thermally oxidized, followed by spray quenching and dust collection. The heat recovered from offgas incineration is temperature controlled to provide the heat for the thermal desorption. Three models are available with soil heating to 600, 1000, and 1400°F.

4. Mobile Retort Unit marketed by Covenant Environmental Technologies, Incorporated is a semi-continuous batch process with indirect firing in which the soil is heated to temperatures in excess of 1,500°F in the absence of air. In the process, the soil is essentially dried by removal of water vapor and VOCs by passing it though a stainless steel cylinder (retort chamber) by an auger drive. The air emissions are controlled by passing them through a baghouse for dust removal followed by a shell and tube exchanger where water and hydrocarbon vapors are condensed.

5. Thermal Desorption Unit marketed by DBA, Incorporated is a continuous process in which the soil is heated to 450°F in a system composed of a primary unit (rotary kiln), a secondary unit (thermal oxidizer), and ancillary components such as control house and discharge augers/conveyors. The offgas VOCs are carried in the air stream through a cyclone, then to a baghouse for final particulate removal, and then to the thermal oxidizer where the VOCs are destroyed to 99 percent or greater.

3.4.6.2 Data Review

Technology Category:	Pretreatment or Thermal Treatment (depending on the particular process)
Technology Names:	Thermal Desorption
Commercial Name:	Low Temperature Thermal Treatment, Low Temperature Thermal Aeration, Tandem SRU, Mobile Retort Unit, Thermal Desorption
Commercial Capacity:	25 to 100 tons/hr.
Demonstrated Capacity or demonstration plans:	This is established and fully demonstrated technology.

Applicable to:	Yes	No
Contaminated soil	x	
Contaminated metal		x
Combustible waste		x
Cemented sludges, concrete, brick, etc.		x
Uncemented sludges	x	
Salts		
Nitrates		x
Other salts		x
Mixed waste types	x	
Drums of liquids		x
Aqueous liquids	x	
Acids	x (higher vapor pressures)	
Organic liquids	x	
Halogenated	x	

	Yes	No
Nonhalogenated	x	
Organophosphates	x	
Gas cylinders		x
High activity waste	x	
Pyrophoric materials	x (at temperatures less than LEL)	
Lead wastes		x
Asbestos		x

Restrictions on feed form: The following limitations must be considered and provisionally allowed for in the final ISV design process;

- o Particle size should be reasonably uniform and less than 1/8 to 1/4 inch dia.
- o Feed must not be containerized for processing
- o Feed should be well mixed and fairly homogeneous

Pretreatment requirements: (in addition to limitations noted above)	<u>Yes</u>	<u>No</u>
Total excavation required	x	
Miscellaneous debris removed	x	
Oversize rocks removed	x	
Retrieval:		
Waste removal from containers	x	
Sorting (if yes, describe)	x (no containers must be fed)	
Sizing (if yes, to what size particle)	x (less than 1/4 inch dia.)	

Level of worker exposure: Total excavation is required; however some technologies address the excavation to minimize exposure. Typically this technology is used where VOCs are primary source of contaminants. It is not known whether the process can be operated remotely, but provisionally it should be possible.

Offgas characteristics treatment system: The offgas treatment system is composed of baghouses/cyclones in series with VOC removal and/or destruction. Metals and radionuclides should in general not be in the offgases.

Fate of volatile radionuclides: If this technology is employed for mixed waste applications, the temperature of the thermal processing should preclude the presence of radionuclides in the vapor state. The soil after processing should still contain the radionuclides to be treated by a separate means, or where applicable be returned to the excavation pit.

Fate of volatile and semivolatile metals:	Same as above for subsequent handling/disposal of process residuals from volatile radionuclides.
Liquid wastes:	This criterion will vary substantially from one vendor to next for thermal desorption, so should be a major consideration in the selection of the specific vendor's wastewater generation potential.
Further stabilization required?	Yes, if there is a requirement for remediation of heavy metals and/or radionuclides.

Will the following contaminants be processed into a stabilized waste form?

PCBs:	Most thermal desorption technologies do not reach sufficiently high temperatures to remove PCBs significantly. One vendor, Thermotech Systems Corporation offers a model for high temperature desorption (1400°F) which is specifically to remove PCBs from a contaminated soil. This technology at the higher temperature will tend to volatilize some heavy metals and therefore has limitations.
RCRA-metals:	This technology is not designed for handling/remediating RCRA metals but may be used in conjunction with other technologies that do.
Reducing agents (hydrazine):	unknown at this time
Ammonia:	Expected to be vaporized into offgas
Sr-90:	Not used for remediation of radionuclides, but may be used in conjunction with other technologies for this requirement.

Utility Requirements:	Vendor specific requirements vary considerably. Many employ some form of energy recovery.
Costs:	\$50 to \$150 per ton of soil treated is an average range taken from most of the thermal desorption technologies but it is expected that this cost data does not reflect actual costs for mixed waste treatment applications which should be substantially higher.

Vendors, Contacts, References:

VISITT 3.0 database, thermal desorption technology

3.4.6.3 Data Gaps

Thermal desorption is an established technology for removal of organics from soils. Other data should be available to establish the level to which various organic contaminants of concern in the SDA could be removed by the technology. Vendor estimates of capital and operating costs could be obtained based on estimated volumes of soil and particular organic contaminants. Vendor information is also required to better determine pretreatment requirements and costs. Little if any data are available on treatment of radioactive waste.

3.4.7 Supercritical Water Oxidation

3.4.7.1 Description

Supercritical water oxidation (SCWO) is a process for destroying organic constituents in waste by oxidation in the medium of water at conditions above the critical temperature (374°C) and critical pressure (22 MPa) of water. Process equipment upstream of the reactor, such as high pressure pumps, compressors, exchangers, and heaters, pressurize and heat the feeds to reactor conditions. Process equipment downstream of the reactor is used to separate solids, liquids and gases in the reactor effluent, as well as cool and depressurize the effluent. Effluents from the SCWO include gaseous oxidation products, waste water, and solid inorganic feed and product materials.

At supercritical conditions, water has extremely high solvating properties for organics, promoting high destruction efficiencies in residence times of seconds. Destruction efficiencies of 99.9999% can usually be achieved at temperatures of 600-650°C.

The high pressure of the SCWO process allows for relatively easy containment of both feed and effluent streams. Products of incomplete oxidation will be contained in a liquid phase which can be sampled and stored or recycled if necessary prior to discharge. SCWO systems can have very low rates of gaseous emissions and minimal air pollution control equipment. Even with no treatment, emissions of NO_x and CO are typically in the low ppm range and particulates and hydrogen halides are well scrubbed by the liquid present in the system.

3.4.7.2 Data Review

Technology Category:	Oxidation
Technology Names:	Supercritical Water Oxidation, Hydrothermal Oxidation
Commercial Capacity:	5 gpm, based on 10% organic feed (Huntsman Corp SCWO unit)
Demonstrated Capacity: or demonstration plans	Testing of simulated DOE mixed wastes and hazardous Naval wastes is presently being performed in Modar's 500 gpd pilot plant; procurement of a 1000 gpd SCWO hazardous waste test bed, which was to be used to exhaustively test simulated DOE mixed waste types and process components, was recently canceled.

SCWO is applicable to liquid waste streams, both aqueous and organic. The process is not applicable to wastes with a high inorganic content unless solids are reduced to less than 100 microns and are "nonsticky," that is, not salts such as chlorides, carbonates and sulfates. The process has potential applicability to organic sludges, organic solids, and soils, but additional development would likely be required.

Restrictions on feed form: For processing with SCWO, organic wastes need to be diluted with water to between 5% and 20%. Supplemental fuel is added to aqueous wastes with less than about 2% organic. Solid particles must be less than 100 microns. Treatment of buried waste would require retrieval, removal or waste from containers, and then either extensive sorting and particle size reduction or extraction of organic contaminants by a solvent or steam.

Measurements of performance: The primary performance measurement is organic destruction efficiency, which is typically 99.99-99.9999%.

Level of worker exposure: Remote operation is possible, but has not been demonstrated. Testing to date with radionuclide surrogates has shown poor recovery of surrogates in the effluent streams, suggesting deposition of surrogates within the process equipment and piping that may require high maintenance.

Offgas characteristics treatment system: Effluent from the SCWO reactor is typically quenched, cooled, and depressurized, and separated into gas, liquid and solid streams. No treatment is anticipated to be required for the gaseous stream other than a carbon bed for trace organic and mercury removal and HEPA filters for particulate. If desired, oxygen can easily be recovered for recycle and CO_2 can be recovered and retained as a liquid or high pressure gas.

Fate of volatile radionuclides: Tritium would be converted to HTO (tritiated water) and build up in the recycle water. Release of ^{14}C could be eliminated by retaining CO_2. Radioactive halogens would be converted to salts.

Fate of volatile and semivolatile metals: Carbon filters on both gaseous and liquid effluents are expected to be needed to remove mercury. Other volatile metals are expected to be contained in the liquid effluent.

Liquid wastes: SCWO can be designed with no liquid effluent by using evaporation and other water treatment methods to recycle water, and solidifying the net water produced.

Solid wastes: Further stabilization would be required for the solids waste from high-chloride content wastes amd wastes containing RCRA-hazardous metals.

SCWO will destroy PCBs and convert hydrazine and ammonia to nitrogen and water. Radionuclides are generally expected to be oxidized, but data is needed to better establish the chemistry of radionuclides at supercritical water conditions.

Utility Requirements:	No unusual utilities or chemicals requirements. Water usage would be minimized by recycling water.
Costs:	Costs estimates have been made of supercritical water oxidation units treating a variety of industrial and government wastes (see References 3-5). These estimates, if scaled to a waste capacity of 5,000 gpd, give a capital cost of $1.7-2.3 million and operating costs of $400-530 K per year for a 5,000 GPD unit. Actual costs for a SCWO treating SDA wastes are expected to be several times higher than these estimates due to additional costs for pretreatment equipment, solid waste stabilization, and control and containment of radionuclides present in mixed waste. Additional demonstration and testing of SCWO with a greater variety of DOE waste types expected would also be required.

Vendors, Contacts, References:

1. Modar, Inc., 14 Tech Circle, Natick, MA 01760
William R. Killilea, Vice President (508) 655-7741

2. Eco Waste Technologies, Inc., 2305 Donely Dr., Suite 108, Austin, TX 78758
Mr. Roy McBrayer, Director of Process Development (512) 837-9961

3. Stone & Webster Engineering Corporation, *Assessment and Development of an Industrial Wet Oxidation System for Burning Waste and Low-Grade Fuels*, DOE/ID/12711-1, September, 1989.

4. R. Kirts, "Supercritical Water Oxidation of Hazardous Wastes," *Proceedings of the Workshop on Federal Programs Involving Supercritical Water Oxidation, July 6-7, 1992, Gaithersburg, Md*, NISTIR-4920, pp. 111-137.

5. M. Modell, *Treatment of Pulp Mill Sludges by Supercritical Water Oxidation, Final Report*, DOE/CE/40914-T1, July, 1990.

6. R. B. Kidman, K. S. Tsuji, *Preliminary Cost Comparison of Advanced Oxidation Processes*, LA-12221-MS, June, 1992.

7. R. F. Weston, Inc., *Supercritical Fluid (SCF) Technologies: Assessment of Applicability to Installation Restoration Processes, Draft Final Report*, U.S. Army Environmental Center Report, November, 1993.

8. VISITT 3.0 database, Supercritical Water Oxidation Technology

9. J. W. Tester, H. R. Holgate, F. J. Armellini, P. A. Webley, W. R. Killilea, G. T. Hong, H. E. Barner, "Supercritical Water Oxidation Technology: A Review of Process Development and Fundamental Research," *1991 ACS Symposium Series, Emerging Technologies for Hazardous Waste Management III, October 1-3, 1991, Atlanta Georgia,* MIT-EL91-003, Revision, March 25, 1992.

10. EPA, *Engineering Bulletin on Supercritical Water Oxidation*, EPA/540/S-92/006, September, 1992

11. C. Shapiro, K. Garcia, J. Beller, *Treatment of Simulated Mixed Waste with Supercritical Water Oxidation*, EGG-WTD-10700, April, 1993 (Draft).

12. T. T. Bramlette, B. E. Mills, K. R. Hencken, M. E. Brynildson, S. C. Johnson, J. M. Hruby, H. C. Feemster, B. C. Odegard, M. Modell, *Destruction of DOE/DP Surrogate Wastes with Supercritical Water Oxidation Technology*, SAND90-8229, November, 1990.

3.4.7.3 Data Gaps

At its present state of development, SCWO has potential for providing high destruction efficiency to hazardous organics in aqueous or liquid organic waste streams from other treatment units in a system treating SDA waste. However, considerable development and scale up would be required if SCWO were to be used to treat SDA soil.

3.4.8 Soil Washing - Organics

3.4.8.1 Description

Soil washing processes utilize size separation, chemical extraction and phase separation steps to remove contaminants from soils. Size separation steps may include crushing, screening, hydraulic classification, gravity concentration, froth flotation or others. Typically a high percentage of organic contaminants are contained on the smaller soil particles, and, once separated, larger size pebbles and rocks do not need further treatment. Smaller particle fractions are then contacted with one or more solvents, which may be either organic or aqueous. To remove organics, aqueous solvents require additives such as surfactants. The solvent is typically recovered, resulting in a waste highly concentrated in the contaminant organics. Soil washing processes typically operate at near ambient conditions of temperature and pressure.

3.4.8.2 Data Review

Technology Category:	Chemical or biological separations
Technology Names:	Soil washing, solvent extraction, soil restoration

Commercial Name: Numerous commercial names such as Solv-Ex (SRE, Inc.,) BEST (Resources Conservation Co.) or The SEG Soil Washing System (Scientific Ecology Group, Inc.)

Applicability: Soil washing processes are most applicable to sandy soils, large amounts of clay and silt will reduce effectiveness or escalate costs. Depending on the process, water content or soil temperature may also be important.

Effectiveness (degree of separation and product quality)

Targeted separation(s): Processes can target specific compounds, groups of compounds or a wide variety of both organics and metals simultaneously.

Separation efficiency or efficiencies: Typical removal efficiencies are 90-95%, but can be lower or higher. In a pilot demonstration of the SEG soil washing process on a Y-12 waste, 510 pounds of uranium and mercury contaminated river sediment, uranium was reduced from 100-200 ppm to 40-80 ppm; mercury from 1000-5000 ppm to 100-300 ppm, and PCBs from 200-500 ppm to 5-20 ppm.

Further treatment may be required for both the treated soil to achieve adequate destruction and the concentrated contaminants to oxidize organics.

Effectiveness (worker exposure): unknown

Effectiveness (secondary waste quantities and composition)

Offgas will contain the VOC's present in the soil and may contain steam, blanket gas, or solvent vapors.

Liquid wastes: The wash fluid, which may be aqueous or organic, will likely require treatment and then be recycled.

Secondary solid wastes: Likely will be minimal.

Implementability

Commercial Capacity and number of commercial facilities: VISITT database includes 10 vendors that have full-scale processes that have actually treated soil containing halogenated organics using soil washing or solvent extraction processes.

Demonstrated Capacity or Demonstration Plans: Capacity of commercial processes is expected to be adequate for the SDA remediation. For example, the On-Site Technologies soil washing process has processing capability for 200-1000 T/day.

Vendors, Contacts, References:

1. EPA VISITT 2.0 Data Base

2. WASTECH, *Soil Washing/Soil Flushing, Volume 3 of Innovative Site Remediation Technology Series*, W. C. Anderson, editor, 1993.

3. Turboscope Vetcon Environmental Services, 2835 Holmes Road, Houston, Texas 77051, Dr. Myron I. Kuhlman, Director of Technology Development, (713) 799-5289

4. Scientific Ecology Group, Inc., Nuclear Waste Technology Dept., 1501 Ardmore Boulevard, Pittsburgh, PA 15221, C. Patrick Keegan or David Grant (412) 247-6255

5. Terra-Kleen Corp., 7321 N. Hammond Ave., Oklahoma City, OK 73132
Alan B. Cash, Vice President, (405) 728-0001

6. Resources Conservation Co., 3630 Cornus Lane, Ellicott City, Maryland 21042
Lanny D. Weimer, Manager, Process Systems Business Development (301) 596-6066

7. SRE, Inc., 158 Princeton St., Nutley, NJ 07110
Sam Sofer, President (201) 661-5192

3.4.8.3 Data Gaps

Although much data are available for soil washing processes for organic removal, differences in soil chemistry and contaminants between sites make treatability studies necessary.

Site characterization data are needed to initially evaluate soil washing processes and provide the basis for bench- and pilot scale testing. Characterization data needed includes:

site geology and hydrogeology
soil type and composition versus depth and surface grid
soil chemistry
amount of contaminated soil, and
range, concentration, and variability of contaminants in the soil.

The analytical data from Pit 9 soil samples (114 samples according to the Cleanup Specification) will be helpful in providing a part of the RI/FS data needed and in defining sampling and soil analysis for the remainder of the pits and trenches.

Bench and pilot scale test data may then be needed to determine the effectiveness of soil washing to remove the specified contaminants from SDA soil. Guidelines and procedures for soil washing treatability studies are explained in *Guide to Conducting Treatability Studies Under*

CERCLA: Soil Washing, EPA/540/2-91/020A, September, 1991.

The Pit 9 remediation process contains the BEST process for removal of organics from soil. The POP test did not include a test of the BEST process except to determine the solubility of plutonium in the soil washing solvent.

3.4.9 Soil Washing - Metals and Radionuclides

3.4.9.1 Description

Heavy metals and radionuclides can also be removed by soil washing processes, which may also be referred to as acid extraction or leaching processes. The soil is typically separated into two or more fractions according to size, washed with an aqueous solution, and then dewatered. The clean soil is returned and the liquid phase further treated to concentrate the contaminants and recover the solution for recycle. The concentrated solution can be solidified or stabilized by several techniques, such as calcining, precipitating, or making into a cement. Depending on the metals to be removed, the wash solution may be acidic, basic, or contain chelating agents or other additives. Most of the soil washing processes are derived from the minerals processing industry.

3.4.9.2 Data Review

Technology Category:	Chemical or biological separations
Technology Names:	Soil washing, solvent extraction, soil restoration
Commercial Names:	Numerous commercial names such as The SEG Soil Washing System (Scientific Ecology Group, Inc.) or The Westinghouse Soil Washing System
Applicability	Soil washing processes are most applicable to sandy soils, large amounts of clay and silt will reduce effectiveness or escalate costs.

Effectiveness (degree of separation and product quality)

Targeted separation(s): Processes can target specific compounds, groups of compounds or a wide variety of both organics and metals simultaneously.

Separation efficiency or efficiencies: Typical removal efficiencies are 90-95%, but can be lower or higher. In a pilot demonstration of the SEG soil washing process on a Y-12 waste, 510 pounds of uranium and mercury contaminated river sediment, uranium was reduced from 100-200 ppm to 40-80 ppm; mercury from 1000-5000 ppm to 100-300 ppm, and PCBs from 200-500 ppm to 5-20 ppm.

Further treatment may be required for both the treated soil to achieve adequate stabilization for metal and/or radionuclide contaminants.

Effectiveness (worker exposure): unknown

Effectiveness (secondary waste quantities and composition)

Offgas will contain the VOC's present in the soil and may contain steam, blanket gas, or solvent vapors.

Liquid wastes: The wash fluid, which may be aqueous or organic, will likely require treatment and then be recycled.

Secondary solid wastes: Likely will be minimal.

Implementability

Commercial Capacity and number of commercial facilities: VISITT database includes 6 vendors that have full-scale processes that have actually treated soil contaminated with radionuclides by soil washing processes. The six vendors have a combined total of 33 units planned, in design, or under construction plus 30 constructed units, although it is not known how many of these units are designed for radionuclide-contaminated soil.

Demonstrated Capacity or Demonstration Plans: Capacity of commercial processes is expected to be adequate for the SDA remediation. For example, the On-Site Technologies soil washing process has processing capability for 200-1000 T/day.

Vendors, Contacts, References:

1. EPA VISITT 2.0 Data Base

2. WASTECH, *Soil Washing/Soil Flushing, Volume 3 of Innovative Site Remediation Technology Series*, W. C. Anderson, editor, 1993.

3. U.S. EPA, Assessment of Technologies for the Remediation of Radioactively Contaminated Superfund Sites, EPA/540/2-90/001, January, 1990

4. B&W Nuclear Environmental Services, Inc., 2220 Langhorne Rd, Lynchburg, Virginia 24501, L. P. Williams, V. P Business Development (804) 948-4610

5. Turboscope Vetcon Environmental Services, 2835 Holmes Road, Houston, Texas 77051, Dr. Myron I. Kuhlman, Director of Technology Development, (713) 799-5289

6. Scientific Ecology Group, Inc., Nuclear Waste Technology Dept., 1501 Ardmore Boulevard, Pittsburgh, PA 15221, C. Patrick Keegan or David Grant (412) 247-6255

7. Bergmann USA, 1550 Airport Rd, Gallatin, TN 37066
Richard P. Travor, Vice President and General Manager (615) 452-5500

8. Westinghouse Remediation Services, Inc., 675 Park North Boulevard, Building F, Suite 100, Clarkston, Georgia 30021, William E. Norton, Senior Engineer
(404) 299-4736

9. Lockheed Corporation, 980 Kelly Johnson Dr., Las Vegas, NV 89119
Ron May, Manager of Engineering (702) 897-3626

3.4.9.3 Data Gaps

Treatability studies are needed for radionuclide leaching or extraction processes to determine the effectiveness of the process, as well as design and operating variables. The Pit 9 POP test of Waste Management Environmental Services' proposed treatment process included three tests of the SOIL*EX process for removal of radionuclides. The three tests used three combinations of Rocky Flats sludges and INEL soil, however, Bi and Mn were used as radionuclide surrogates. Test acceptance criteria were met.

3.4.10 Offgas Treatment

3.4.10.1 Description

Quenching/metals condensation Most equipment cannot withstand the temperatures of gaseous effluent from thermal treatment units, thus some type of cooling is required prior to cleaning offgas to contaminant levels acceptable for release to the atmosphere. Quenching can be achieved by boilers, heat exchangers, air dilution, or water injection. Boilers and heat exchangers can recover heat but may be subject to fouling or corrosion. Air dilution is simple but requires large volumes of air which results in larger size downstream air pollution control equipment. Water injection is also relatively simple, but may cause corrosion or result in a relatively large volume of liquid waste.

Acid gas removal Acid gases are removed from offgases by reaction with an alkali reagent. Acid gases react to form salts, which are then collected as dry particulate or sludge or are dissolved in a liquid solution. Acid gas removal devices are usually classified as either wet, dry, or semidry. Wet acid gas removal includes packed-bed scrubbers, tray scrubbers, and wet fluidized bed scrubbers. Removal efficiencies for both HCl and SO_2 are typically greater than 99% for each of these types, even with a rate of alkali only about 5% in excess of stoichiometric. In dry acid gas removal, a dry powder alkali reagent is injected into the flue gas. It is usually necessary to use 50-300% excess alkali reagent. Acid gas removal efficiencies are typically 90-99.9% for HCl and 50-99% for SO_2. To achieve efficiencies in the higher end of these ranges, a reactor chamber providing sufficient residence time is required.

In the semidry process, know as spray dryer absorption, a alkali solution or slurry is sprayed into a cylindrical chamber through which offgases are flowing. Acid gases are absorbed into the small liquid reagent droplets and react to form dissolved salts. Heat from the offgases evaporates the water, cooling the offgas and resulting in a solid particles of salt, unreacted alkali, and other solids such as flyash present in the offgas from the thermal treatment unit. With a 50-100% excess reagent, removal efficiencies are typically 99% for HCL and 95% for SO_2.

NO_x Removal Primary abatement technologies for NO_x abatement involve changes in the combustion process to minimize NO_x formation. These include the use of oxygen rather than air for combustion, limiting the amount of oxygen available at the peak combustion temperature and lowering the combustion zone temperature. Removal of NO_x from the offgas requires a reaction step to reduce NO_x to nitrogen gas. Catalytic reduction uses ammonia to convert NO_x to nitrogen and water. Operating temperature is typically 500-800°F. To achieve removal efficiencies in the 90-95% range, excess ammonia is required, and results in an effluent ammonia concentration of up to 50 ppm. Most NO_x catalytic reduction reactors also oxidize carbon monoxide and other products of incomplete combustion to CO_2 and water.

Noncatalytic reduction processes for NO_x removal are also commercially available. Operating temperatures are generally higher than the catalytic processes, and some use hydrogen or urea rather than ammonia for reduction.

Particulate removal Removal of particulate from offgases is a well established technology. Selection of specific devices depends primarily upon the amount of particulate and the size distribution of particles in the offgas. Dry particulate removal techniques include metal filters, bag houses which are also called fabric filters, electrostatic precipitators, gravity separators, cyclone separators, impingement separators, and high efficiency particulate filters (HEPAs). Each of these methods results in a purified gas stream and a dry solids product. For remediation of the SDA pits and trenches, particulate removed in the offgas treatment unit would likely be recycled into the waste treatment system.

A wide variety of wet scrubbing systems are also available, including venturi scubbers, rotary atomizing wet scrubbers, free-jet scrubbers, ionizing wet scrubbers and others. Because they utilize water to entrap particulate, many of these wet scrubbers can serve multiple purposes of quenching a high temperature offgas, condensing mercury and other volatile metals, removal of acid gas by an alkali added to the scrubbing water and removing particulate.

Mercury and hazardous metals removal The volatility temperatures of Cr, Ni, Be, Ag, Ba, Sb, Tl, and Pb are above 1160°F, and thus will be condensed in the quench step of the offgas treatment. Selenium has a volatility temperature of 604°F and cadmium of 417°F, and will also condense in the offgas treatment process. Although the volatility temperature of arsenic is only 90°F, arsenic will be present as oxide, which, being soluble in water, would be removed through wet scrubbing. Data from hazardous waste incinerators indicate metal removal efficiencies for fabric filters are far higher than 95% for most metals except mercury. Mercury can be removed with high efficiency wet scrubbers, or be adsorbed on activated carbon. Activated carbon also adsorbs other heavy metals.

Removal of products of incomplete combustion Products of incomplete combustion (PICs) include dioxins, furans, and polyaromatic hydrocarbons and possibly carbon monoxide and low molecular weight hydrocarbons. Upset conditions in the thermal treatment unit can also cause significant amounts of PICS in the offgas system. The two most common methods for ensuring near total destruction of PICs are activated carbon adsorption and catalytic destruction. Provided PIC concentrations are small, carbon adsorption offers high removal efficiencies at relatively low capital and operating costs, while also being easy to operate and maintain. Catalytic PIC destruction processes operate at temperatures of 300-1300°F, and typically achieve destruction efficiencies of 90-99%.

Volatile radionuclides removal Volatile radionuclides present in the SDA waste include tritium, ^{14}C, ^{36}Cl, ^{129}I, and ^{226}Ra. The amount and activity of radium is sufficiently small that removal may not be required. Chlorine and iodine, if present in the offgas, will be removed by the acid gas scrubber. Tritium will be oxidized in thermal or nonthermal oxidation treatment to tritiated water. If the buildup of tritium becomes excessive, the contaminated water would need to be solidified into cement. Fixation of $^{14}CO_2$ can be achieved using an industrial process to produce $CaCO_3$. A calcium hydroxide slurry is fed to the top of a fixation tower, with CO_2-containing offgas entering the bottom. The resulting calcium carbonate slurry is filtered, dried, and packaged for disposal. Threshhold levels and release limits of tritium and ^{14}C need to be determined to evaluate whether fixation processes would be required.

3.4.10.2 Data Review

Although different treatment systems will have variations in their offgas treatment processes, any thermal treatment process, in-situ or ex-situ, as well as many nonthermal processes will require offgas treatment. As a whole, offgas treatment technology is well developed.

Commercial Capacity: Offgas treatment systems are widely used in a great variety of industries, including nuclear fuel reprocessing, hazardous waste incineration, municipal waste incineration, petrochemicals manufacture, the pulp and paper industry, and smelting operations. Capacity of these industrial systems is well within and beyond what would be required for the SDA remediation. Experience has also been gained from offgas systems on radioactive waste incinerators, both in the United States and abroad.

Measurements of performance or efficiency: Offgas treatment efficiencies will be directly tied to emission limits, and will likely include CO, total hydrocarbons, sulfur dioxide, particulate less than 10 microns, principal organic hazardous constituents (POHCs), dioxins, HCl, chlorine, NO_x, and RCRA-hazardous metals.

Fate of volatile radionuclides: Volatile radionuclides will be removed to the specified limits by the offgas treatment system. Tritium removal will require removal of water, and possibly, for some systems, a reactor to ensure that all tritium is in the form of tritiated water rather than tritium gas. ^{14}C as CO_2 can be removed by many commercial methods, and halogens will be removed in the acid gas scrubbing steps.

Fate of volatile and semivolatile metals: Volatile metals will be removed to the specified limits by the offgas treatment system by condensation, filtration, adsorption and other methods.

Liquid wastes: Systems can be designed as either dry, without liquid waste; or wet, in which case waste would need to be treated or stabilized.

Solid wastes: For most thermal treatment systems, solid wastes containing volatile metals such as mercury and cadmium will come from the offgas treatment system. Spent solid adsorbents and HEPA and other filter media will also be wastes from the offgas system.

Vendors, Contacts, References:

1. D. Dalton, E. M. Steverson, G. L. Anderson, *Air Pollution Control in Thermal Treatment*, EGG-WTD-10038, March, 1992.

2. EG&G, Idaho, *Mixed and Low-Level Waste Treatment Facility Project, Volume 3, Waste Treatment Technologies*, EGG-WMO-10244, September, 1992.

3. A. G. Croff, *An Evaluation of Options Relative to the Fixation and Disposal of ^{14}C-Contaminated CO_2 and $CaCO_3$*, ORNL/TM-5171, April, 1976

3.4.10.3 Data Gaps

As emission standards become better defined, a more thorough review of offgas treatment capabilities should be made, including estimating offgas treatment system costs. A more detailed review of methods for fixation of CO_2 is also needed to ensure technical feasibility.

3.4.11 Portland cement

3.4.11.1 Description

Portland cement has wide application as a stabilization/solidification (s/s) agent for immobilization of wastes. In this type of system, cement and an aqueous waste, or cement, water, and a waste are mixed to form a solid waste form. Other solid materials such as ion-exchange resin, filter sludges or mechanical assemblies are either added to the mixture or are encapsulated in the cement. As the cement begins to set or cure, a colloidal gel of indefinite composition and structure is formed. Over the curing time period, the gel swells and forms a solid matrix composed of interlacing, thin densely packed silicate fibrils. Contaminants in the waste being treated are incorporated into the interstices of the cement matrix. The resultant solid formed has a high compressive strength, excellent durability, low leachability and when properly formulated, leaves no free water. The addition of selected sorbents and/or emulsifiers often overcomes the problem of contaminant migration through the rather porous solid matrix, and consequently lowers the leaching losses from the treated wastes.

Stabilization techniques are generally those whose beneficial action is primarily through limiting the solubility or mobility of the contaminants with or without change or improvement in the physical characteristics of the waste. Portland Cement based s/s systems are widely applicable for both hazardous and mixed waste requirements to achieve a high degree of immobilization. They offer effective treatment of organics (up to 10 wt. percent), most inorganics (except sulfates and halides), heavy metals, and radioactive materials. This form of technology has been used extensively for treatment of Low-Level Waste (LLW) in the nuclear power industry. Portland cement s/s has been determined to be the Best Demonstrated Available Technology (BDAT) to satisfy RCRA hazardous waste treatment standards.

3.4.11.2 Data Review

Technology Category:	Stabilization
Technology Names:	Portland Cement Systems
Commercial Name:	Portland Cement S/S Systems (14 major vendors)
Commercial Capacity:	Mobil Plants: 150,000 gallons per day of waste. Site Specific Plants: capacities set by appropriate economy-of-scale design to meet remediation requirements.
Demonstrated Capacity:	Proven technology. A specific application on SDA treatment requirements would typically be proven in laboratory formulations before a field application was designed. A formal demonstration would then be carried out on a pilot plant scale of 1/20 to 1/40 of full scale.

Applicable to:	Yes		No
Contaminated soil			x (typically)
Contaminated metal	x		
Combustible waste	x		
Cemented sludges, concrete, brick, etc.			x
Uncemented sludges	x		
Salts			
Nitrates			x
Other salts	x		
Mixed waste types	x		
Drums of liquids	x (may be accomplished in-drum)		
Aqueous liquids	x		
Acids	x		
Organic liquids	x (limited to 10 wt % of mix)		
Halogenated	x (certain halides only, conc. dependent)		
Nonhalogenated	x		
Organophosphates	x		
Gas cylinders		x	
High activity waste			x (typically)
Pyrophoric materials		x	
Lead wastes	x		
Asbestos			x (typically)

Restrictions on feed form:

- o Loose solids not greater than 1/8 inch diameter
- o Drum waste may be solidified in-drum, if applicable waste type
- o Although the feedstock may be liquid, slurry, or loose solid, premixing must be considered to provide a homogeneous feedstock with a similar consistency to provide best economy for a continuous process; if batch process then economy may favor less waste stream mixing and more special formulations.
- o Sealed containers of liquids or gases require special provisions
- o Very large containers and miscellaneous debris will typically favor another treatment technology.

Pretreatment requirements:
(in addition to limitations noted above): Extremely definitive waste characterization is needed, to ensure proper mixture formulation

Level of worker exposure: This technology is typically more labor intensive unless the waste type(s) are highly consistent and a continuous or semi-continuous process is justified. In general, the degree of personnel exposure is fairly high with this technology.

Process cannot be operated remotely, unless there is a continuous processing requirement called for and the waste is highly consistent in contaminant type and concentration.

Offgas characteristics and treatment system: A minimal gas cleanup system will typically be required for this technology for the mixing and curing applications when volatiles can be generated. The offgas should be relatively benign since little heat is added to the material being treated.

Fate of volatile radionuclides? This technology is used extensively in the nuclear power industry to treat LLW. The solid product will pass LDR and TCLP criteria for radionuclides and heavy metals.

Fate of volatile and semivolatile metals: Volatile and semi-volatile metals are compatible with s/s since there is very little temperature elevation during the curing process (160 to 190°F). The LDR criteria should be met or exceeded, but demonstration or bench scale tests should be carried out for specific waste mix for proof.

Liquid wastes: Essentially all organic liquids up to a maximum of 10 weight percent can be effectively treated with cement s/s. Certain inorganic wastes may retard setting or be more easily leached from the cement matrix. Known limitations for inorganic liquids are sulfates and certain halides.

Further stabilization required: None required.

Will the following contaminants be processed into a stabilized waste form?

PCBs: Yes.
RCRA-metals: Yes.
Reducing agents (hydrazine): Concentration dependent.
Ammonia: Unknown.

Sr-90: Yes.
Cs-137: Yes.
TRU elements: Yes.

Utility Requirements: To be determined

Costs:

The estimated cost for treatment is \$40 to \$100 per ton for a mobil treatment system. (EPA estimate from Handbook for Stabilization/Solidification of Hazardous Wastes, 1986) This does not include the cost of bench- and pilot-scale testing.

Vendor contacts, References:

1. Handbook for Stabilization/Solidification of Hazardous Wastes, Environmental Protection Agency, Publ # EPA/540?2-86/001, June 1986.

2. Mixed and Low-Level Waste Treatment Facility Project, Vol 3, Section 10, September, 1992

3. Standard Handbook of Hazardous Waste Treatment and Disposal; Harry M. Freeman, Editor in Chief, 1988.

4. Solidification and Stabilization of Hazardous Wastes, Parts 1 & 2, April, 1989, M. John Cullinane Jr., Larry M. Jones, Hazardous Materials Control Magazine.

3.4.11.3 Data Gaps

Although this is an established technology, application to remediation of the SDA should be proven in laboratory formulations before a field application is designed. A formal demonstration would then be carried out on a pilot plant scale of 1/20 to 1/40 of full scale. The first questions are how much and what types of waste would be solidified by this technology. Considerably more waste characterization data would be needed if applied to retrieved waste than if applied to secondary waste streams from the entire treatment system, such as excess waste water, tritiated water, ^{14}C-contaminated waste, etc.

3.4.12 Polymer Cement

3.2.12.1 Description

The stabilization/solidification and immobilization mechanism employed by these systems to entrap and hold contaminants is sometimes referred to as microencapsulation. They immobilize the waste by encapsulating it in plastic matrix. Plastic microencapsulation has been used effectively/successfully in nuclear waste disposal and is adaptable to special industrial waste. The two most widely accepted polymer systems in use at present are the Vinyl Ester Styrene (VES) system and the Sulfur Polymer Cement (SPC) system. In the VES system, very soluble wastes can be treated since the free water is also immobilized when it is dispersed in the VES resin binder. When the binder hardens, the free water and waste become trapped in the cell structure of the plastic matrix. The technique involves dispersion contacting in the heated plastic, followed by letting the mixture cool to form a rigid but deformable solid. This is typically done in fiber or metal drums to provide the treated material in a convenient shape for transport.

In the SPC system a small quantity of dicyclopentadiene and oligomers of cyclopentadiene are added to elemental sulfur and the resultant polymer is a thermoplastic. It is known for its ability to provide complete containment of the waste constituents and as such is used for specific wastes where cost is not a limiting factor. It has applications for high concentrations of mineral acids, corrosive electrolytes, and salt solutions in which there are few useful alternatives to microencapsulation. SPC has excellent mechanical stability and corrosion resistance to most minerals. One distinct advantage that SPC has over Portland cement systems is in the processing itself. In Portland cement systems, if there is an inadvertent stoppage of flow in the process due to an upset condition, the system processing equipment becomes solidified and typically requires disposal. In SPC systems, a process flow interruption requires only reheating the equipment to initiate processing again with no set-up and permanently plugged equipment.

The SPC process involves mixing dry wastes, elemental sulfur, and additives together and heating the mixture to about 270°F. The waste form has successfully passed EPA TCLP testing for toxic heavy metals and most NRC testing under 10 CFR 61.

It should be noted that the SPC and VES processes are both considered developmental for mixed waste treatment, but results to date are very encouraging.

3.4.12.2 Data Review

Technology category: Stabilization
Technology Name: Polymer Cement Systems
Commercial Name: Sulfur Polymer Cement, Urea-Formaldehyde, Vinyl Ester Styrene, and Polyethylene
Commercial Capacity:

In-situ treatment of contaminated soil: 1,500 cu yd per 8-hr shift.
Mobil plants for treatment of liquids and light slurries: 150,000 gallons per 24 hr day.
In-drum processing: 4.5 drums per hr.
Site Specific Plants: capacities set by appropriate economy-of-scale design to meet remediation requirements.

Demonstrated Capacity: Proven Technology. Demonstration would only be required to establish a remotely operated approach if job mandated.

Applicable to:	Yes	No
Contaminated soil	x (typically)	
Contaminated metal	x	
Combustible waste	x	
Cemented sludges, concrete, brick, etc.		x
Uncemented sludges	x	

Salts	
Nitrates	x
Other salts	x (evaluate chemical compatibility/reactivity)
Mixed waste types	x
Drums of liquids	x (may be accomplished in-drum)
Aqueous liquids	x
Acids	x (chemical reactivity must be evaluated very carefully)
Organic liquids	x
Halogenated	x (s/s formulation dependent)
Nonhalogenated	x
Organophosphates	x
Gas cylinders	x
High activity waste	x (s/s formulation dependent)
Pyrophoric materials	x (s/s formulation dependent)
Lead wastes	x
Asbestos	x

Restrictions on feed form:

- o Loose solids not greater than 1/8 inch diameter (ground or delumped)
- o Drum waste may be solidified in-drum, if applicable waste type
- o Although the feedstock may be liquid, slurry, or loose solid, premixing must be considered to provide a homogeneous feedstock with a similar consistency to provide best economy for a continuous process; if batch process then economy may favor less waste stream mixing and more special formulations.
- o Sealed containers of liquids or gases require special provisions
- o Very large containers and miscellaneous debris will typically favor another treatment technology.

Pretreatment requirements:
(in addition to limitations noted above): Extremely definitive waste characterization is needed, to ensure proper mixture formulation

Level of worker exposure: This technology is typically more labor intensive than other cement stabilization techniques unless the waste type(s) are highly consistent and a continuous or semi-continuous process is justified. In general, the degree of personnel exposure is fairly high with this technology.

Process can be operated remotely, but demonstration may be required to prove effectiveness for an in-situ application. If ex-situ where in-drum technique is employed, robotics approach is probably not applicable. If mobile processing of ex-situ application is warranted, a robotics approach is probably not applicable.

Offgas characteristics and treatment system: A minimal gas cleanup system will typically be required for this technology for the mixing and curing applications when volatiles can be generated. The offgas should be relatively benign since little heat is added to the material being treated. If in-situ application is employed where solidifying agents are injected into soil and some gross disturbance of soil takes place, an enclosure with separate air emission control system may be required for particulate and some minimal amount of VOC emission control(s).

Fate of volatile radionuclides? The waste form for the SPC process has successfully passed EPA TCLP testing for toxic heavy metals and most NRC testing under 10 CFR 61. Laboratory testing has shown that SPC is resistant to leaching of both radionuclides and hazardous metals.

Fate of volatile and semivolatile metals? See above.

Liquid wastes: Essentially all organic liquids up to a maximum of 10 weight percent can be effectively treated with some form of s/s. The SPC process is most applicable to high concentrations of mineral acids, corrosive electrolytes, and salt solutions. All s/s processes are specifically formulation dependent upon the actual waste being treated and the range of variations during normal remediation processing. The need to homogenize the feed stream is extremely important when s/s is used.

Further stabilization required? None required.

Will the following contaminants be processed into a stabilized waste form? (if so, what form?)

PCBs: Yes.
RCRA-metals: Typically, but test data is needed. Barium, silver and selenium may not be stabilized.
Reducing agents (hydrazine): Concentration dependent.
Ammonia: Unknown.

Sr-90: Yes.
Cs-137: Yes.
TRU elements: Yes.

Utility Requirements: To be determined on actual site based upon an economy-of-scale approach. A good source book to evaluate actual experienced utility requirements is the "Handbook for Stabilization/Solidification of Hazardous Wastes", EPA/540/2-86/001, or a more recent and updated version of same.

Costs: The estimated cost for treatment is $40 to $100 per ton for a mobil treatment system. (EPA estimate from Handbook for Stabilization/Solidification of Hazardous Wastes) The experienced treatment cost for drum ex-situ treatment is $224/drum (1986 data). The experienced cost for in-situ treatment using a backhoe on a large RCRA sites was $10 to $20 per cu yd in approx. (1986 data). All of the above cost will be somewhat higher for mixed waste treatment in current dollars.

Vendor contacts, References:

1. Handbook for Stabilization/Solidification of Hazardous Wastes, Environmental Protection Agency, Publ # EPA/540/2-86/001, June 1986.

2. Mixed and Low-Level Waste Treatment Facility Project, Vol 3, Section 10, September, 1992

3. Standard Handbook of Hazardous Waste Treatment and Disposal; Harry M. Freeman, Editor in Chief, 1988.

4. Solidification and Stabilization of HazardousWastes, Parts 1 & 2, April, 1989, M. John Cullinane Jr., Larry M. Jones, Hazardous Materials Control Magazine.

3.4.12.3 Data Gaps

The SPC and VES processes are both considered developmental for mixed waste treatment, and hence data from treatability studies is needed for proper evaluation, once the waste types for which they are being considered is determined. Long term data regarding stability of polymer cement, such as resistance to biodegradation, are needed.

3.4.13 Pozzolanic Processes

3.4.13.1 Description

Pozzolanic processes employ an immobilization mechanism to entrap and hold the contaminants in a solid matrix form. The stabilization/solidification and immobilization mechanism employed by these systems to entrap and hold contaminants is sometimes referred to as microencapsulation. The basic differences in the pozzanlanic processes are the type of binders used. All pozzanlanic processes employ inorganic binders which differentiates them from polymer cement systems which use organic binders. The binders used in pozzanlanic processes are varying combinations of hydraulic cements, lime, pozzalans, gypsum, and silicates. In these systems, water is removed in the hydration reactions that result.

Pozzanlan/Fly Ash processes use a finely divided, noncrystalline silica in fly ash and the calcium in lime to produce low-strength cementation. Pozzolan-Portland systems use Portland cement and fly ash or other pozzolan materials to produce a stronger type of waste/concrete composite. The waste containment is produced by microencapsulation in the concrete matrix. Soluble silicates may be added to accelerate hardening and metal containment.

The type of pozzolanic process used is based upon the type of contaminants to be treated/encapsulated and the resultant economics of processing. The Pozzolan/Fly Ash system is relatively inexpensive but the cured composites may not be as durable or control contaminant leaching as well as Portland cement systems. Oil and grease may physically interfere to reduce the containment of contaminants. Pozzolan-Portland systems by contrast have can be formulated to yield exceptional strength and retain selected contaminants more effectively. Research in the nuclear, mixed waste field has shown that waste turbine oil and greases can be mixed into cement blends if dispersing agents are used and the proper mixing system is employed. In summary, pozzolanic, cement-based processes are more versatile than lime-fly ash processes, can be formulated for exceptional strength, and have been found to retain selected contaminants effectively.

3.4.13.2 Data Review

Technology Category:	Stabilization
Technology Name:	Pozzolanic Processes
Commercial Name:	Pozzolan/Fly Ash System, Pozzolan-Portland Systems, Silicate-Based System, and Lime Based System

Commercial Capacity:

In-situ treatment of contaminated soil: 1,500 cu yd per 8-hr shift.

Mobil Plants for treatment of liquids and light slurries have capacities of 150,000 gallons per 24 hr day.

In-drum processing: 4.5 drums per hr.

Site Specific Plants: capacities set by appropriate economy-of-scale design to meet remediation requirements.

There is almost no limit to the capacity for processing of a fixed plant design, but economics usually favor a mobile facility since it can be decontaminated after use and employed again at a different site for a different requirement.

Demonstrated Capacity: Proven Technology. Demonstration would only be required to establish a robotics approach if job mandated.

Applicable to:	Yes	No
Contaminated soil	x (typically)	
Contaminated metal	x	
Combustible waste	x	
Cemented sludges, concrete, brick, etc.		x (unless size reduced)
Uncemented sludges	x	
Salts		
Nitrates	x	
Other salts	x (evaluate chemical compatibility/reactivity)	
Mixed waste types	x	
Drums of liquids	x (may be accomplished in-drum)	
Aqueous liquids	x	
Acids	x (chemical reactivity must be evaluated very carefully)	
Organic liquids	x (10 weight % or less, by formulation)	
Halogenated	x (s/s formulation dependent)	
Nonhalogenated	x	
Organophosphates	x	
Gas cylinders		x
High activity waste	x (s/s formulation dependent)	
Pyrophoric materials	x (s/s formulation dependent)	
Lead wastes	x	
Asbestos	x	

Restrictions on feed form:

- o Loose solids not greater than 1/8 inch diameter (ground or delumped)
- o Drum waste may be solidified in-drum, if applicable waste type
- o Although the feedstock may be liquid, slurry, or loose solid, premixing must be considered to provide a homogeneous feedstock with a similar consistency to provide best economy for a continuous process; if batch process then economy may favor less waste stream mixing and more special formulations.
- o Sealed containers of liquids or gases require special provisions
- o Very large containers and miscellaneous debris will typically favor another treatment technology, unless selective separation is used; in which case, a combination of s/s with another technology may be justified.

Pretreatment requirements:
(in addition to limitations noted above): Extremely definitive waste characterization is needed, to ensure proper mixture formulation

Level of worker exposure: If ex situ processing is required, then this technology is typically fairly labor intensive and personnel exposure could be significant, unless the waste type(s) are homogenized to be highly consistent. If the waste can effectively be homogenized for consistency, a continuous or semi-continuous process may be employed that can greatly minimize personnel exposure. If in situ processing is employed, there should be very little personnel exposure.

Process can be operated remotely, but demonstration may be required to prove effectiveness for an in-situ application. If ex-situ where in-drum technique is employed, robotics approach may be accomplished but the process would be much more complex, and may not be economical. If mobile processing is warranted, a robotics approach will not be applicable.

Offgas characteristics and treatment system: A minimal gas cleanup system will typically be required for this technology for the mixing and curing applications when volatiles can be generated. The offgas should be relatively benign since little heat is added to the material being treated. The only heat required will be the heat of hydration generated and will result in a maximum temperature of around 160 degrees Fahrenheit. If in-situ application is employed where solidifying agents are injected into soil and some gross disturbance of soil takes place, an enclosure with separate air emission control system may be required for particulate and some minimal amount of VOC emission control(s).

Fate of volatile radionuclides? The U.S. Nuclear Regulatory Commission (NRC) has developed a position on characteristics that solidified waste must have to be acceptable. The waste types that the NRC focuses on are low-level radioactive, so the standard may not be entirely applicable to nonradioactive hazardous waste. Radioactive materials are entirely compatible with all types of solidification/stabilization techniques and can generally be successfully applied.

Fate of volatile and semivolatile metals? Can be effectively treated to meet regulatory requirements.

Liquid wastes: Essentially all organic liquids up to a maximum of 10 weight percent can be effectively treated with pozzolanic processes, but the pozzolan-cement processes are generally the most effective. Aqueous waste can be effectively treated. The specific blend of liquids present in the waste type(s) may favor one form of pozzonlanic process. This is typically determined by a treatability study in which specific formulations are evaluated until the best type process meeting the regulatory needs and best overall economics is determined.

Additional stabilization required? None required.

Will the following contaminants be processed into a stabilized waste form?

PCBs: Yes.
RCRA-metals: Yes.
Reducing agents (hydrazine): Yes.
Ammonia: Unknown.
Sr-90: Yes.
Cs-137: Yes.
TRU elements; Yes.

Utility Requirements: To be determined on actual site based upon an economy-of-scale approach. A good source book to evaluate actual experienced utility requirements is the "Handbook for Stabilization/Solidification of Hazardous Wastes", EPA/540/2-86/001, or a more recent and updated version of same.

Costs:

The estimated cost for treatment is $40 to $100 per ton for a mobil treatment system. (EPA estimate from Handbook for Stabilization/Solidification of Hazardous Wastes) The experienced treatment cost for drum ex-situ treatment is $224/drum. (1986 data) The experienced cost for in-situ treatment using a backhoe on a large RCRA sites was $10 to $20 per cu yd in approx. (1986 data). All of the above cost will be somewhat higher for mixed waste treatment.

Vendor contacts, References:

1. Handbook for Stabilization/Solidification of Hazardous Wastes, Environmental Protection Agency, Publ # EPA/540/2-86/001, June 1986.

2. Mixed and Low-Level Waste Treatment Facility Project, Vol 3, Section 10, September, 1992

3. Standard Handbook of Hazardous Waste Treatment and Disposal; Harry M. Freeman, Editor in Chief, 1988.

4. Solidification and Stabilization of HazardousWastes, Parts 1 & 2, April, 1989, M. John Cullinane Jr., Larry M. Jones, Hazardous Materials Control Magazine.

3.4.13.3 Data Gaps

Like other stabilization technologies, design and formulation of Pozzanlanic cements require well defined feed/waste streams. Effectiveness and cost can be better evaluated once retrieved or secondary waste streams are defined for which stabilization is being considered.

3.4.14 Decontamination Processes

Reviews of decontamination technologies, including descriptions, status, science/technology needs, implementation needs, contacts and references are contained in Volume 3 of *Idaho National Engineering Laboratory Decontamination and Decommissioning Technology Logic Diagram*, EG&G-WTD-11104, January 1994. A summary of various decontamination technologies and data gaps is listed below, taken from the INEL Logic Diagram. Only technologies with the status of "accepted" (commercially available) are listed.

Surface Cleaning Alternative	Data Gaps or Development Needs
1. Compressed-Air CO_2 pellet blasting	Extensive tests needed to provide accurate cost estimates
2. High pressure water	Development of water recycle system and robotics control system
3. Superheated water	Development of water recycle system and robotics control system
4. Hot water (low pressure)	Development of water recycle system
5. Steam cleaning	Development of water recycle system and robotics control system
6. Strippable coatings	
7. Vacuuming	Development of reusable filters
8. Ultrasonic cleaning	

Chemical Surface Cleaning Alternative	General data gap for this alternative: Well defined form (chemical species) of contamination and substrate materials
1. Inorganic acid	
2. Caustic treatment	
3. Electropolishing	Development of primary and secondary waste treatment and recycle
4. Organic solvents	
5. Phosphoric acids	Adaptation of system to meet regulatory requirements, waste treatment development
6. Oxalic acid	Adaptation of system to meet regulatory requirements, waste treatment development
7. Hydrochloric acid	Adaptation of system to meet regulatory requirements

8. Detergents and surfactants	None
9. Bleaching	Development of improved application techniques
10. Acid etching	Adaptation of system to meet regulatory requirements, waste treatment development

Mechanical Substrate Surface Removal Alternative

1. Ultra-high pressure water	Development of water recycle system and robotics control system
2. Shot blasting	Demonstration plant, waste minimization development
3. Scabblers/scarifiers	Adaptation to robotics control system
4. Grit blasting	Test facility to determine decontamination factors, process automation, and other design data
5. Ice blasting	Adaptation to a robotics control system
6. Plastic pellet blasting	Development of system to separate and package contaminants and process waste
7. Hand grinding	Development of remotely operated system and offgas treatment system
8. Drill & spall	None
9. High pressure jet spalling	None

Thermal Substrate Surface Removal

1. Flaming

5.0 REFERENCES

1. *A Comprehensive Inventory of Radiological and Nonradiological Contaminants in Waste Buried in the Subsurface Disposal Area of the INEL RWMC During the Years 1952-1983, Volumes 1-4,* EGG-WM-10903, June, 1994.

2. C. A. Loehr, B. H. Becker, D. E. Burns, R. M. Huntley, S. M. Rood, P. Sinton, T. H. Smith, *Preliminary Scoping Risk Assessment for Waste Pits, Trenches, and Soil Vaults at the Subsurface Disposal Area, Idaho National Engineering Laboratory,* EGG-WM-11181, May, 1994.

3. *Human Health Contaminant Screening Analysis for the Subsurface Disposal Area*, April, 1995.

4. Record of Decision, *Declaration for Pit 9 at the Radioactive Waste Management Complex Subsurface Disposal Area*, October, 1993.

5. C. J. Smith, *A History of the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory*, EG&G Idaho Internal Technical Report, WM-F1-81-003, Rev. 3, July, 1985, p. 77.

6. *Environmental and Other Evaluations of Alternatives for Management of Defense Transuranic Waste at the Idaho National Engineering Laboratory, Volume 1,* IDO-10103, April, 1982, p. 1-4.

7. D. A. Arrenholz, J. L. Knight, *Historical Report of Transuranic Waste Pits and Trenches at the Subsurface Disposal Area of the Radioactive Waste Management Complex at the INEL*, EG&G Idaho Internal Technical Report WTD-91-027, August, 1991.

8. Lockheed Idaho Technologies Company Interdepartmental Correspondence, T. R. Meachum to D. J. Kuhns, *Revision of ER&WM-EDF-0007-93, Areas and Volumes for selected Radioactive Waste Management Complex Pits and Trenches*, TRM-04-95, January 30, 1995.

9. S. O. Bates, *Definition and Compositions of Standard Wastestreams for Evaluation of Buried Waste Integrated Demonstration Treatment Technologies*, EGG-WTD-10660, June, 1993, p. 9.

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11. U.S. Environmental Protection Agency, VISITT 3.0 database, June, 1994.

12. M. C. O'Brien, R. H. Meservey, M. Little, J. S. Ferguson, M. C. Gilmore, *Idaho National Engineering Laboratory Waste Area Groups 1-7 and 10 Technology Logic Diagram, Volumes I-III*, EG&G-WTD-10784, September, 1993, and R. H. Meservey, D. S. Vandel, M. Little, J. S. Ferguson, *Idaho National Engineering Laboratory Decontamination and Decommissioning Technology Logic Diagram, Volumes I-III*, EG&G-WTD-11104, January 1994.

13. EG&G Idaho, *Mixed and Low-Level Waste Treatment Facility Project, Volume 3, Waste Treatment Technologies*, EGG-WMO-10244, September, 1992.

14. F. Feizollahi, W. J. Quapp, H. G. Hempill, F. J. Groffie, *Integrated Thermal Treatment System Study - Phase 1 Results*, EGG-MS-11211, Volume 1, July, 1994.

15. F. Feizollahi, W. J. Quapp, *Integrated Thermal Treatment System Study - Phase 2 Results, Third Draft*, LITCO-MS-11211, January, 1995.

16. R. Geimer, T. Hertzler, R. Gillins, G. L. Anderson, *Assessment of Incineration and Melting Treatment Technologies for RWMC Buried Waste*, EGG-WTD-10035, February, 1992.

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20. RWMC Area Topographic Survey, EG&G Drawing 175610, Rev. 2, October 16, 1991.

21. SDA Contour Map, EG&G Drawing 356697, December 4, 1987.

APPENDIX A

OU 7-13/14 Response Action Alternatives Chart
Prepared by Darwin Grigg

General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability/Availability	Cost 2
NoAction	Not Applicable	Not Applicable	Not effective for some nuclides due to potential groundwater contamination or intrusion into some SDA pits and trenches.	This alternative is less than that currently implemented at the RWMC. Might require waiver of ARARs by regulatory agencies.	Capital -none O&M - none
Institutional Control	Limitations on Access	Legal restrictions on access and use	100-year institutional control will provide short-term prevention of intrusion into the pits and trenches; institutional control over longer time spans may be necessary to prevents modification of caps/covers and monitoring systems. Ground water protection and gas release not affected by any access restrictions.	Current practice. Has been successful at limiting human intrusion. Does not limit animal intrusion. Requires someenforcement.	Capital - none O&M - very low
		Deed restrictions	Deed restrictions if enforced will prevent intrusion into the pits and trenches; institutional control over longer time spans may be necessary. Ground water protection and gas release not affected by any access restrictions.	Current practice. Has been successful at limiting human intrusion. Requires some enforcement.	Capital - none O&M -very low
		Fencing and other barriers	Physical barriers prevent intrusion into the pits and trenches as long as they are maintained and patrolled; institutional control over longer time spans may be necessary. Ground water protection and gas release not affected by any access restrictions.	Current practice. Has been successful at limiting human and some animal intrusion. Requires fence maintenance.	Capital - very low O&M -very low
	Maintenance of Existing cap	Native Soil Cover System. Subsidence Correction and Placement of up to 5 m of Cover soil during next 100 years	Existing operational scenario. Provides better protection from infiltration of precipitation and from erosion than rock or synthetic covers due to increased transpiration from plants and some self healing properties of clay in natural soil. Meets RAO's for TRU and Volatile Organics. Reactor Waste RAO's may also be met if credit given for existing packaging, and lack of existing migration of contaminants over 50 years is recognized.	Current practice. Requires continued action on a limited basis by D[illegible] nd responsible agencies. Implementation follows current practices.	Capital - very low O&M - low
	Monitoring	Ground water monitoring	Effective in monitoring subsurface migration for most contaminants. Monitoring does not tell source. Prescence of the reactor waste nuclides from other locales is possible.	Current practice. Monitoring technology for both short and long term is proven, commercially available. May requre establishment by regulatory agencies of deminimus levels before future irrigation is permitted. Advanced monitoring technology is currently being developed.	Capital - very low O&M - low
	Flood And Erosion Control	Diversion Ditches Dike Construction	Has been very effective in preventing catastrophic water inundation. Further construction could provide protection against a 1000 year flood. Not effective against organic or C-14 gas releases or routine precipitation.	Conventional Construction. Technology is immediately available. Already implemented to some extent. Maintenance required.	Capital - low O&M - low
		Vegetation Establishment	Current vegetation has been effective in providing transpiration for routine precipitation. Not effective for catastrophic water inundation. Further vegetation could provide protection against deep penetration from spring runoff. Not effective against organic or C-14 gas releases or catastrophic flooding.	Conventional Construction. Technology is immediately available. Already implemented to some extent. Maintenance (watering) might be requred for non-native species.	Capital - very low O&M - very low
		Grading Of Cover For Drainage, Surface Water Erosion, And Runoff Control	Most effective method in preventing both routine and catastrophic episodic water inundation. Used with other construction to provide protection against a 1000 year flood. Not effective against organic or C-14 gas releases.	Conventional Construction. Technology is immediately available. Already implemented to some extent. Maintenance required.	Capital - very low O&M - low
		Rip - Rap (rock) Surface Armoring	More effective in preventing wind erosion and intrusion than clay cap, membrane and soil cover materials. Some protection against catastrophic water inundation. Assists other construction in protection against a 1000 year flood. Not effective against organic or C-14 gas releases or penetration by routine precipitation.	Conventional Construction. Technology is immediately available. Maintenance required.	Capital - low O&M - very low
		Above Ground Solidified Waste Vault Cover System	Most effective intrusion protection possible of all "hardened" cover systems (basaltic rock, plasma arc, asphalt and concrete). Cover for vault includes contouring/sloping, native soil, vegetation, so transpiration of most precipitation and runoff of high episodic spring precipitation better than at-grade covers. Most effective cover system against flooding since cap is well above grade and the cement-wasteform-block-"armored". Entire system resistant to even running water. Sheer bulk and mass makes cover effective against subsidence within vault and below in SDA. Some gas retardation for C-14 gases and organic vapors. Excellent shielding against radiation and wind erosion. TSA and other stored waste might be incorporated in vault so waste, overall disposal cost, and space is minimized.	Conventional Construction. Technology is immediately available. Development might be required depending on type of waste incorporated into cap and the cap solidification material.	Capital - mod O&M - low

In Situ Containment, Stabilization

Surface Containment, Capping

Technology	Effectiveness	Implementability	Cost
Plasma Arc Glass Cover	Might be effective as an intrusion barrier. Binds surface contaminants in glass and destroys organics. Some infiltration of precipitation if cracking occurs. Similar to natural basaltic cover. Not a gas barrier.	Application still in R&D phase. Not demonstrated. Screened out as technology not available by FY-97.	Capital - mod/high O&M - low
Soil and Rock Cover System	Not as effective as native soil; transpiration not aided by plants. Depth of infiltration from spring precipitation further than in native soil. No gas retardation for C-14 gases and organic vapors. Intrusion protection similar to plasma arc, asphalt and concrete covers.	Conventional Construction. Technology is immediately available. Little maintenance required depending on vegetationchosen.	Capital - very low O&M - low
Asphalt Cover	As effective as concrete and plasma arc cap. Permeability lower than native rock cover. Potential for infiltration of precipitation over time based on extent of cracking from weathering . Provides some intrusion protection. Not a gas tight barrier	Conventional Construction. Technology is immediately available. Maintenance required similar to a road surface to repair cracks.	Capital - mod O&M - low
Composite Clay, Sand, and Soil Cover System	More effective at stopping moisture infiltration of precipitation than soil/rock or soil systems. About equally as effective at stopping erosion provided clay does not desicate. Non native soils may not support indigenous INEL vegetation. Little protection from intrusion, similar to present native soil cover. Some gas barrier properties if the clay remains moist.	Conventional Construction. Technology is immediately available. Maintenance required for repairing clay dessication cracking.	Capital - low O&M - low
Geosynthetic/ Common Soil Cover System	Effective; provides moderate to high level of protection from infiltration of precipitation and from erosion. No long-term (+100 yrs) information on geosynthetic life expectancy. Membrane acts as a gas barrier. Some intrusion protection from membrane.	Conventional Construction. Technology is immediately available. Maintenance required.	Capital - low O&M - low
Composite Geomembrane/Clay Cover System	Effective; provides high level of protection from infiltration of precipitation and from erosion. No long-term (+100 yrs) information on geosynthetic life expectancy. Membrane and clay act as an improved gas barrier over either alone. Some intrusion protection from membrane.	Conventional Construction. Technology is immediately available. Less maintenance required than all clay system as liner can be used to help prevent clay dessication cracking.	Capital - low O&M - low
Concrete Cover with Overlying Geomembrane Liner and Soil Cover	Effective for protection from infiltration of precipitation and highly effective at providing erosion protection. No long-term (+100 yrs) information on geosynthetic life expectancy. Concrete provides intrusion protection and membrane acts as a gas barrier	Conventional Construction, Technology is immediately available. Mininimal maintenance required as concrete not exposed to elements as it would be in a road suface.	Capital - mod O&M - low
RCRA Composite Cover	Effective; provides high level of protection from infiltration of precipitation and from erosion. Clay and membrane provide a gas barrier. Excellent for long term monitoring of caps effectiveness. Slight intrusion protection.	Conventional Construction. Technology is immediately available. Maintenance required after 50 years. Cap provides a monitoring capability.	Capital - mod O&M - low
UMTRA Composite Cover	Good intrusion protection. Gas barrier from clay. Not as effective transpiration properties as native soil caps with vegetation. Considered most effective in arid areas.	Conventional Construction. Technology is immediately available. Little Maintenance required cap should have a 300 year life in arid areas.	Capital - mod O&M - low
Sheet Piles, metal	Effective short term physical barrier for lateral organic vapor movement. Long-term effectiveness based on durability of the metal.	Not applicable to certain soils with large boulders or if large object might be encountered. Has been implemented at Hanford as a migration barrier but no demonstration at INEL.	Capital - low O&M - low
Jet Grout Portland, Polymer or Natural Analog CementingAgents 5	Jet grouting is the most effective application method for applying below grade stabilization agents (grouts) to encapsulate buried waste. It is most effective in terms of filling voids in waste and the soil, intimately mixing grout with waste and clayey soils, eliminating the potential for subsidence, and in variety of grouts that can be applied. Jet grouting particulate grouts (portland cement) are able to penetrate INEL soil. Void reduction in buried waste containers is greater that 70% and soil voids are reduced at least 50%. With the proper grout jet grouting creates a cemented monolith to mitigate water infiltration , waste migration providing a high level of protection from infiltration of precipitation and intrusion protection. Hematite, Apatite, and Calcites grouts thus applied provide both a physical and chemical interaction with TRU/Heavy metal contaminated wastes (see Insitu Treatment) Polymers provide mainly a monolithic physical barrier preventing water intrusion and pit subsidence. Jet grouting with cementing agents like portland, apatite, hematite, and calcite will retard but not eliminate the migration of VOC's. Polymer grouts do better in this regards. Reactor Waste such as carbonates and solid metal components will be immobilized. Hematite, apatite, calcite, portland or polymer materials have shown long term durability in E8 Rem gamma fields.	Proof-of-concept should be completed by FY-96; if positive, technology would be immediately implementable. Earliest avaliability is start of FY-97. Jet grouted monolith may decrease permeability around organic source terms and interfere with vapor vacuum extraction; therefore implementability should follow other in situ organic remediation if organic vapors are to be removed. Jet grouting in regions where there is potential to bring high gamma field materials to the surface has never been demonstrated. Special shielding and possible remote operation may be required.	Capital - mod O&M - low
Monolithic Confinement	Effective at sealing fractured basalt from moisture penetration. One to three orders of magnitude change in hydraulic conductivity attainable. Long-term effectiveness positive because presence of natural calcite material in basalt has not moved. Not 100% effective because of complex nature of basaltic flows. Does limit permeation of VOC material through the basalt. Will effect other insitu treatments in the basalt such as vapor vacuum extraction. Should stop solutions of water and dissolved carbonates limiting flow of C-14. Should also stop downward flow of other dissolved fission products.	Proof-of-concept demonstrated in FY-94. Drill hole and high pressure injection of common oil field grouts such as portland Immediately available and implementable. Must be used in conjunction with a good cap or will create a "bathtub" effective in the waste that will increase contact time and thus leaching to water.	Capital - mod O&M - low

In-situ Stabilization/ Below Grade Isolation, Physical Interaction with Waste	Vertical Impermeable Barriers (Slurry Walls)	Vertical barriers applied by trenching is a proven technology in the construction and mining industry to limit sideward water movement usually in saturated humid environments. Effectiveness to stop water flow in an unsaturated arid environment, along basalt fractures, and along the basalt soil interface is unknown. Determining effectiveness of any mechanical barrier difficult in situ . VOC transport through such barriers is diminished somewhat. Useful as a pretreatment before retrieval to shore waste seam and prevent secondary contamination.	Barrier technology is immediately available for mitigating lateral VOC movement provided the pit boundaries are known and organic venting across this barrier boundary is not desired.	Capital - mod O&M - low
	Horizontal Impermeable Barriers	Horizantal barriers applied by angular trenching or well techniques not a proven technology. Effectiveness to stop waste leachate flow in an unsaturated arid environment is unknown. Determining effectiveness of barrier difficult in situ . These barriers more difficult to make and verify. than vertical. Effectiveness in Idaho's clayey soil will proabably not be much more than the natural clay in the soil.	Barrier technology is unavailable for Heavy metals/TRU, VOC and Reactor Wastes. Both effectiveness and FY-97 avalabilty caused this to be rejected as a process option.	Capital - mod O&M - low
	Dynamic Compaction	Both intrusive (INEL hammer drill lance) and non intrusive (Savannah River dropped concrete cylinder technique) methods exist; however, only the intrusive technique has been demonstrated and verified for INEL buried waste conditions. Some short term gain in decreasing voids for loosely dumped INEL debris. because of clay soil resistance to compaction. Should be effective long-term to decrease future subsidence and minimize maintenance but Savannah River Studies show some voids remain. The non intrusive method has essentially been done with the heavy equipment compaction used on most of the SDA during maintenance. Both non-intrusive and intrusive techniques are ineffective to contain VOC's and actually may enhance release by puncturing or rupturing drums with free liquids. Compaction should be as effective for both short and long term on reactor waste though any intrusive compaction may be limited by reactor vessel and large objects in LLW pits at the SDA. Much of the subsidence has already occurred and further compaction may show little further density increase.	Technology immediately implementable for non-intrusive technique; however, special shielding and possible remote operation would be required for intrusive techniques. It has been used on buried waste contaminated with Heavy Metals/TRU, VOC's and Reactor Wastes.	Capital - low O&M - very low
	Jet Grout Walls vertical/horizontal	Proven technology in construction industries particularly in dam building. Effective impermeable barrier in the short-term provided the construction can be verified. Long-term effectiveness is unknown. Jet Grouting application more penetrating than any other in situ application method. Use with speciality grouts discussed under chemical barriers. Large buried objects may divert flow and decrease effectiveness.	Jet grouting to make walls is immediately available. Verification without visual confirmation can be difficult. Horizontal drilling still in development, but expected to be implementable by FY-96. Most applications in the past decade have been in large construction projects rather than waste remediation. Large buried objects may divert flow disrupting wall integrity and/or use excessive amounts of grout.	Capital - mod O&M - mod
Non-thermal	In Situ Photon or Neutron Transmutation	Conceptual technology that involves placement of a portable nuclear accelerator in a borehole palced in sityu within the buried waste stream. Neutron or photon bombardment transmutes the long lived radionuclides into ones with shorter half lives. Not effective for hazardous metals and organics. Does not create a waste form for these nuclides. Potential as a pretreatment for specific high TRU waste streams.	Not yet demonstrated. Still in research phase. Eliminated due top availability and effectivenss for bureid waste streams.	Capital -high O&M - high
	Permeate grout treatment specialty grouts	Free gravity flowing grout into buried waste is most effective in sandy soils or with very low viscosity chemical grouts no longer in use (ORNL). Use of natural analog grouts such as iron/ phosphorous-rich materials are only as effective as the penetration into waste and soil which is minimal. Very little mixing with this application method. Permeation depends on very low viscosity grouts not mechanical or pressure enhanced mixing. The similarity of the process to natural sedimentation processes gives some confidence in long term stability . Permeate grouting not suitable for silty clay soils and current formulations will not penetrate INEL-SDA soil types.	Permeation grouting technology is immediately available and easily implementable. Solutions applicable to clayey soils are in R&D phase not implementable by FY-97. Rejected due to insufficient penetration in INEL soils.	Capital - mod O&M - low
	Pressure Grout Barrier/treatment specialty grouts	Pressure grouting (50-500 psi) is more effective at penetration than permeate grouting. Pressure grouting particulate grouts unable to penetrate the INEL soil types though some other grout formulations might work. When combined with dynamic compaction provides E-5cm/s conductivity compared to E-3cm/s conductivity in soil/waste seams; VOC's migration might be slightly hindered in the short term. Long term effect might be maintained using a natural analog grout. These novel grouting materials such as iron/ phosphorous-rich materials have several features that improve pressure effectiveness: Pressure grouting application method is still relatively dependent on grout formulation and gives a slightly more intimate mixing of grout and waste than permeation grouting. Pressure grouting is usually more effective than permeating grouting. Long-term effectiveness based more on grout properties (such as natural analog similarity to natural rocks) than the application method in most soils.	Low pressure grouting along with dynamic compaction have been demonstrated at INEL in 1986.	Capital - low O&M - low
	Jet Grout Barrier/treatment specialty grouts	Jet grouting (1000-6000 psi) is the most effective grout application methods in terms of variety of grouts applied and intimate mixing with waste and within clayey soils. Jet grouting particulate grouts able to penetrate INEL soil. Hematite, Apatite, and Calcites grouts thus applied provide both a chemical interaction with TRU/Heavy metal contaminated wastes. These grouts chemically lock up these particular elements. Jet grouting with cementing agents like portland, apatite, hematite, and calcite do not chemically retard migration of VOC's. Reactor Waste such as carbonates and solid metal components will have some chemical immobilization. Jet grouting is able to apply a wide variety of grout formulations and with effective mixing would bind C-14 carbonates, iodides, both hazardous and radioactive radionuclides. The void filling and subsidence reducing properties remain. Long-term effectiveness is based more on grout properties and grout waste interaction than in physical stabilization when this application method is used..	Jet grouting in buried waste is similar to that to make walls thus is immediately available. Verification of void fill without visual confirmation can be difficult. A few applications in the past decade have been in large landfills. Contamination control critical for addressing contamination of Reactor Waste and TRU in drilling spoils and on drill lance.	Capital - mod O&M - low

In Situ Treatment; Below Grade Applications, Chemical Interaction Some Stabilization	Soil Mixing Barrier/treatment specialty grouts	As effective as jet grouting for buried homogenous waste such as contaminated sediments or sludges. Most any grout can be used and current augers can mix large volumes. Not effective for buried debris type waste, large objects, and containerized waste. Mixing effectiveness depends not on permeability of soil or sludge but on associated debris, rocks and large objects. INEL clayey soil can enhance certain grouts effectiveness when mixed thoroughly. More controllable than jet or pressure grouting so effective barriers can be constructed which are as durable as the solidified grout/soil mixture is. Mixing might encourage VOC movement and is generally not used for VOC remediation.	Soil mixing technology is currently used by oil and geo service and environmental remediation companies. Used to mix homogenous process waste and sludge in any type of soils. Difficult to implement where containers, construction debris and large objects might be encountered.	Capital - mod O&M - low
	Chemical Barriers	TRU, Heavy metal, Carbonate, Iodide migration can be mitigated by chemical even regardless of total water permeability. Specialized grouts have been and are being developed to form this combined moisture and chemical barrier. Laboratory studies show iron/phosphoric-rich materials attract and sequestor migrating hazardous and radioactive metals. Short term effectiveness excellent, in this capacity, as perfect water impermeability is not required. Long term effectiveness has promise due to the natural analog aspect. Natural rocks at the INEL contains calcium, phosphorus and iron. Although not demonstrated, chemical grouts may provide more extensive penetration for pressure grouting. For VOC's some polymeric materials might be effective in containing vapor by chemical absorption and assisting natural organic breakdown. Phosphoric/ iron rich materials should provide some temporary retardation of VOC flow. For reactor wastes C-14, Tc-99 and I-129 polymers, calcium/phosphoric/iron rich materials should all prevent migration of carbonates and other migrating fission product materials. Long-term resilience of the material and thus maintenance of migration barrier appears good from a natural analog perspective. Effectiveness for most chemical barriers is highly contaminant-specific.	Proof of concept has been demonstrated but no full scale, in-situ demonstration has been performed for any radionuclide. Specialty grout solutions for chemical barriers and grout curtains are in R&D phase, but expected to be implementable by FY-96. Polymer grouts with ion exchange capacity are in R&D phase but may be demonstrated in FY-96. Their susceptibility to VOC still needs testing. Addition of chemical agent may require additional approval/permitting by DOE and state/federal agencies.	Capital - mod O&M - low
	Vapor Vacuum Extraction	Demonstrated technology for removing organics from contaminated soils. Effectiveness limited by ratio of vapor pressure to solubility for each specific contaminant. Effectiveness may be enhanced by heating soil using microwave heating., electrical elements. No benefit for reactor heavy metals and TRU. Might be used to volatilize Tc-99 or I-129 for removal and subsequent absorption.	Commercially available. Demonstrated at Superfund sites and full scale at the INEL, where over one thousand pounds of carbon tetrachloride has been removed. Implementation depends on soil/clay/organic interactions. A passive system that requires no pumping is under study and will be ready by FY-97.	Capital -low O&M - very low
	Electrokinetics	Proof of concept has been demonstrated for organic contaminants. Effective at removing all forms of organic contaminants freely sorbed on soils. Limited application to buried waste sites, unless containers heavily corroded. Limited by soil permeability. Effect on heavy metals unproven.	Requires full scale demonstration and clayey soils. Not effective for INEL wastes and soil. Will not be available by FY-97.	Capital - mod O&M - mod
	In Situ Soil Bioremediation	Proof of concept has been demonstrated ex-situ. Effective at removing organics and nitrates from contaminated soils. Effectiveness highly dependent on availability of moisture in soil. Ineffective for heavy metals, unless some washing system is used. Requires moisture and nutrient addition.	Requires full scale in-situ demonstration in and clayey soils. Not effective for INEL wastes and soil. Will not be available by FY-97	Capital - low O&M - low
	In Situ Groundwater Bioremediation	Has been demonstrated in-situ at Superfund sites. Effective at decomposing organics and nitrates from contaminated water. Effectiveness highly dependent on availability size of gross volume of groundwater source, availability of nutrients. Ineffective for TRU, heavy metals, C-14 carbonate, Iodide unless some washing system is used or the precipitation in insitu is exceptable. Requires monitoring and usually nutrient addition.	Requires full scale in-situ demonstration in INEL type groundwater. Implementing for decomposition of carbon tetrachloride and other halogenated organics that are very difficult organics to decompose needs testing. Could be demonstrated and ready by FY-97.	Capital - low O&M - low
	In Situ Surfactant Flushing	Effective at removing organics, some metals and nitrates from contaminated soil. Effectiveness highly dependent on porosity of soil and attachment of contaminants to soil. Ability to get surfactant to contaminants and verify contact is critical. Effectiveness for TRU, heavy metals, C-14 carbonate, Iodide unknown with most testing based on soil washing systems. Requires monitoring , good geocharacterization, large quantities of water and pumping of surfactant.	Proof of Principle demonstrated in-situ. Requires full scale in-situ demonstration in INEL type soil and buried waste. Implementing for removal of carbon tetrachloride and other halogenated organics that are strongly sorbed to soil needs testing. Not implementable in the FY-97 time frame and not effective for our COC. Use of large quantities of water in situ un acceptable.	Capital - mod O&M - low
Vitrification	Joule Heated In Situ Vitrification	Demonstrated and commercially available for remediating contaminated soils and debris. Technical issue of pressure surges from sealed containers limits use in buried waste sites. Currently limited to depths of 21-23 ft. with 17 ft. optimal, unless staging is used (although greater depths are under development). Documented evidence of Tc-99 incorporation into glass matrix. Iodine incorporation slight but iodine easily absorbed in off gas system. C-14 emitted as a gas may be an emission issue.	Sealed container issue requires resolution; otherwise, technology is commercially available. Prescence of volatile contaminants require advanced secondary treat that needs development especially for C-14	Capital - mod O&M - mod/high
	Joule Heated In Situ Vitrification with Pretreatment	Involves integration of previously demonstrated technologies (ISV with dynamic compaction, vibratory rod drilling, jet grouting.) Proof of principle testing needed, but should resolve sealed container issue and removal of large voids. Encapsulating ability for Reactor Waste similar to other vitrification methods.	Integrated demonstration needed; individual technologies are commercially available.	Capital - mod O&M - mod/high
	Non-Joule Heated In Situ Vitrification	Non-Joule heated, bottom-up vitrification has had preliminary tests on non-contaminated soils. Needs proof-of concept testing on simulated buried waste including sealed containers. Final waste form may not be as effective as Joule heated ISV due to stratification and lack of homogeneity. Encapsulating ability for Reactor Waste similar to other vitrification methods.	Screened out as an undemonstrated technology not available by FY-97.	Capital - mod O&M -mod/high

General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability/Availability	Cost 2
	Retrieval	Archeological (no heavy equipment)	More effective than mechanical methods in removing hazardous source terms selectively with minimal secondary contamination. The most effective method for determining source term removal during retrieval is hand monitoring. Most effective method to limit drum breaching during removal and complete removal of the hazard without extensive secondary waste generated or mixing of TRU, hazardous and reactor wastes. Limited effectiveness for large thru- put excavations or heavy wastes. Protection of worker against VOC, TRU and heavy metals depends on the bubble suits effectiveness. No protection against high gamma fields. Will involve an elaborate contamination control system with soil fixants, misting systems, ventilation and extensive radiological monitoring. Extremely labor intensive, personnel exposure to radiation and chemical hazards.	Routinely used retrieval procedure. Implementable with special waivers and using a high number of radiation workers to meet ALARA goals. Proven in Superfund for most interred waste except large objects which would require heavy equipment for removal. Might be the best method for small "hot spot" removal. Worker safety considerations in radiological, hazardous, explosion, criticality concerns and general construction due to intimate contact with waste would most likely affect implementation. The more restrictive bubble suited operation constraints would increase contact time and exposure to potentially high gamma fields. If the VOC's are separate from the TRU and reactor wastes, the process is immediately implementable. Reactor Waste removal would require a greatly expanded work force of radiation workers to keep applied dose rates low (ALARA goals).	Capital - none O&M - low Capital - low O&M - mod/high
		Bubble suited workers using conventional excavation equipment such as a backhoe.	Most effective retrieval method for mixed type debris removal in throughput, and versatility. More effective than complete manual removal in moving heavy items such as sludge filled drums and large items such as 4x4x8 boxes. Less secondary waste, more selectivity than remote methods. Limited effectiveness for crumbling containers. Less labor intensive, less personnel exposure to radiation and chemical hazards than all manual method though bubble suited entry still required. Limited effectiveness in preventing drum breaching. Fairly complete removal of the hazardous materials. Simplest method to achieve high thru put.	Demonstrated Technology; Most used technique for buried waste retrieval due to high thru-put and versatility. Less contact time for workers than completely manual methods. Might still require regulatory waiver to allow bubble-suited entry in hazardous regions, high fields and with criticality concerns.	Capital - mod O&M - mod
		Manual Retrieval with Bubble Suited Workers using advanced excavation equipment like Innovative End Effectors.	More effective than backhoes for precise waste/ overburden removal. Accuracy of 1/2" and precision of 0.04" achieved in overburden horizontal soil removal mode. Similar precision in vertical removal possible but not demonstrated. Applicable to precision removal of soil near contaminated objects or zone such as removal of overburden soils. Advanced end effectors are more effective than conventional end effectors in removing containers with reduced particulate contamination of surrounding air and clean soils. Not effective at reducing fields or vapor spread except incidentally by the decreased contamination spread or reduced container breakage. Field demonstrated and scalable to 80 yd^3 per day removal rate. Complete removal of solid TRU, mixed reactor debris, liquid organics and associated contaminated soil possible. Same safety concerns as with conventional machinery. Gamma hardening of equipment will be required to perform the operation. With a long boom the technology could be accomplished with a man in a cab with minimal shielding.	Demonstrated Technology; Immediately available for operator retrievals. Requires some modification for remote operation. Demonstrated for basic removal of soil and buried objects.(Pit 9). Similar buried waste retrieval thru put and versatility as conventional machinery but contamination spread much less. Less contamination to workers than completely conventional retrieval methods. Might still require regulatory waiver to allow bubble-suited entry in hazardous regions, high fields and with criticality concerns. Some systems are off the shelf technology. Implementation in a high gamma field not tested.	Capital - mod O&M - mod/high
		Pneumatic/Vacuum soil/waste excavation.	Most effective retrieval method for dry soils and sludge in throughput and contamination control as the entire system is contained. Less effective than manual removal in moving heavy and large debris tems such as lathes and construction debris. Less secondary waste, similar selectivity as remote methods. Less labor intensive, less personnel exposure to radiation and chemical hazards than all manual method. Bubble suits required only for maintenance. More effective than heavy machinery in preventing drum breaching as dry sludges can be sucked out of drums. Fairly complete removal of the hazardous materials. Simplest method to achieve high thru put.	Demonstrated Technology; Used commercially for excavation around utility lines due to selective soil removal and pipe protection. Less contact time than bubbel suited entry and completely manual methods. Not demonstrated at INEL but can be purchased for use by FY-97.	Capital - low O&M - low
		Remote Excavation, Dust Free Dumping, TelerobaticConveyance	Most effective method to remove high gamma field contaminated waste particularly reactor type waste. Completely removes all types of buried and hazardous waste. Remote technologies provide full containment of the excavation. Special integrated conveyance and dust free dumping allows transfer and movement of soil/debris to treatment or packing area. Dust suppression technologies such as HEPA filtered exhaust, electrostatic curtains, ultra-fog misting systems minimize contamination spread primarily for maintenance activities within the containment. Off-gases are treated and monitored. Remote operation minimizes worker exposure. Protective coverings will minimize contamination of excavation equipment, hence creation of secondary waste stream.[1] Excellent short and long term effectiveness because it removes the source term with minimal risk to the worker. Full scale remote operation not demonstrated yet however. Contamination control demonstrated with limited success. Removal of VOC source term possible even if reactor waste/TRU present; More effective retrieval method than any manual method in minimizing worker risk because it separates the source term during retrieval from the worker. Less precise in retrieval of specified areas or containers than manual methods.	Dust-free dumping has been demonstrated. Full scale remote excavators and gantry cranes are available but have not been demonstrated in a buried waste retrieval scenario. Technology available commercially. Through puts will probably be less than equivalent non remote operations. Demonstration of innovative remote end effector and remotely conveyance of waste from dig face to transfer area successful. Removing reactor type buried wastes has never been demonstrated. For reactor waste off the shelf equipment requires gamma hardening. Although some of the technology applications are innovative for mixed hazardous waste retrieval, the individual technologies are developed (essentially "off-the-shelf"). Throughput rate and contamination spread/dust control requires development to be implemented by 1997. Improvements in vision systems and power for conveyance system should be demonstrated in FY-95. A full scale integrated demonstration is planned at the INEL for FY-95 for smaller-scale remote retrieval using a remote gantry cranes. In FY-96 OTD might test remote excavators. Performance of Pit-9 per current schedule will provide large-scale demonstration of TRU buried waste removal by end of FY-96;	Capital - high O&M - high
		Remote Excavation Remote Maintenance	Most effective method to remove high gamma field contaminated waste particularly reactor type waste. Most effective method to separate workers from hazards chemical and radiological of all types of buried waste. Remote technologies provide full containment during the excavation and maintenance of equipment. Dust suppression technologies to minimize contamination spread within the containment are not as important to those of ease of remote maintainability (see appendix of auxiliary engineering options); off-gases are treated and monitored. Remote operation and maintenance minimize worker exposure. Excellent short and long term effectiveness because it removes the source term with minimal risk to the worker. Full scale remote maintenance not demonstrated yet however. Removal of VOC source term possible even if reactor waste/TRU present; Most effective retrieval method in minimizing worker risk because it removes the source term with minimal risk to the worker.	Full scale remote maintenance not demonstrated. Modifications for easy remote maintenance still in conceptual stage. Full scale remote excavators and gantry cranes are available; however, they have not been tested or maintained in a buried waste retrieval scenario. Through puts and operational details are unavailable. High Level Waste technology for remote maintenance on equipment is available; however, the overall process of retrieval and maintenance especially maintenance of innovative technologies for mixed hazardous waste retrieval has not been demonstrated. Individual technologies are developed (essentially "off-the-shelf").	Capital - very high O&M - high
		Mobile Retrieval Facility	Effectiveness as a single source operational platform minimizes contamination. Best method for large area removal, eliminating containment structure. Might be more effective in high gamma fields or TRU particulate zones by eliminating contact or secondary contamination spread.	Never demonstrated; conceptual design stage only; however, short-term and long-term. CRADA possible but rejected as will to develop full scale system in FY-97.	Capital - high O&M - mod

Retrieval, Packaging, Disposal	Packaging, Sorting	Heat Seal (Shrink Fit Plastic Wrap)	Effective contamination control method. Compatible with thermal treatment options. Does not remove free liquids, organics or fines. Does not contain for long term storage but good for transporting containers to disposal or treatment facility.	Technology commercially available and in use for packaging Heavy metals/TRU containers. Might not be implementable for VOC's due to organic decay of plastic and volatility during heat treatment. For reactor waste requires special plastic and gamma hardening of equipment.	Capital - very low O&M - low
		High Density Plastic Macro-Encapsulation of Containers	Effective contamination control method for decaying containers and exposed large objects. Compatible with thermal treatment options. Does not remove free liquids, organics or fines. Can contain for medium term storage. Improved method over shrink wrap for transporting containers to disposal or treatment facility.	Technology commercially available and in use for packaging sludge heavy metals/TRU containers. Demonstrated at INEL for metallic lead containment from leaching and impact. Resistant for some VOC's containment though volatility during heat treatment is unproven. For encapsulating reactor waste requires special plastic and gamma hardening of equipment.	Capital - low O&M - low
		Shred debris and mix with portland or natural analog grout	Effective contamination control method. Compatible with thermal treatment options depending on grout used. Removes free liquids, some organics and fines.	Technology commercially available, however not demonstrated for all SDA buried waste types.	Capital - low O&M - low
		Sizing and separation of contaminated waste stream into heavy and lightly contaminated components	Existing municipal waste processing equipment effectively shred waste and separate into soil and ferromagnetic components. Conventional conveyor/size sorting machines run by additional monitoring technologies are believed to be effective at separating the waste stream based on 10 nCi/gm Pu criterion. Operation and maintenance can be accomplished remotely; conventional containment technologies will confine contaminants. Separation of Reactor Wastes possible but level that could be returned to the pit has not been set.	Immediately implementable uses developed commercial technologies. Separation of TRU at 10 nCi/g level may require some development and verification. Seperation of other nuclides possible but limits have not been set or method tested.	Capital - low O&M - low
		Cryofracture Large Object debris and mix with portland or natural analog grout	Freezing the waste with liquid nitrogen and crushing the waste with a large press greatly reduces spread of VOC's and TRU/heavy metal contamination. It is a safer and more contaminant free shredding operation than conventional shredders as explosives and contaminants are in a frozen matrix. Most effective way to keep volatile reactor waste from the off gas system. Frozen matrix should contain contaminants but special shielding will be required. Compatible with all subsequent packaging or treatment options thermal or grout.	Commercially Available Technology.	Capital - mod O&M - low
Disposal	Interim Storage	Concrete/earthen Bunker	Greater than 20-year life allows RCRA-approved storage. Containment superior for all waste types in both the short and long term. Protects waste from weather and contains particulate and vapor releases in a similar fashion to metal buildings. Provides best intrusion protection (plane crashes, tornadoes) and shielding of all buildings. If constructed from low level waste blocks, wastes and cost minimized	Technology commercially available. In use at the INEL as temporary storage of mixed waste. Carbon filters on drum vents contain VOC's and allow hydrogen venting.	Capital - mod O&M - low
		Metal Buildings	20-year life allows RCRA-approved storage. Containment excellent for all DOE waste types in short term in terms of protection from weather, and containing particulate and vapor releases. No shielding provided by building. Provides wind protection but not as much intrusion protection as concrete bunker.	Technology commercially available and in use at the INEL on similar types of waste. Carbon filters on drum vents contain VOC's and allow hydrogen release.	Capital - mod O&M - low
		Air Support Buildings	Less than 20-year life. Can be erected more quickly than permanent buildings. Containment less effective as the building is at positive pressure, requires air flow, more maintenance and is more susceptible to wind damage.	Technology commercially available and in use at the INEL on similar types of waste. Carbon filters on drum vents contain VOC's and allow hydrogen venting.	Capital - low O&M - low
		WIPP	Removes waste from Idaho. WIPP is a highly engineered repository for above ground stored and retrieved mixed (Heavy Metals/VOC) TRU waste. Minimal treatment needed to produce a waste form meeting WIPP waste acceptance criteria (WAC) thus for any type of TRU waste this is the best long term disposal option. WIPP disposal removes the source from availability. The short term effectiveness depends on method of interim storage. Fission Products as found in reactor waste not certified for WIPP though effectiveness should be better than any other option.	Not implementable at this time. Uses proven technologies. Interim storage facility will be required. Waste must be repackaged to meet transportation requirements and effectively assayed to verify waste meets WIPP WAC. Final disposal to waste repository dependent on availability of WIPP, projected to be 2010. Will require mandate from Congress	Capital - very high O&M - moderate
	Final Disposal	Nevada Test Site Disposal	Involves shipping both stored and retrieved buried TRU waste to NTS. Some waste may be placed in the Low Level Waste Burial area,. Other types such as TRU placed around thermonuclear devices or in former bomb blast holes. Waste is shipped in a 5-year time frame. Further destruction, disassociation and/or transmutation possible in a thermonuclear blast. Long and short term effectiveness comparable with that of waste produced by previous underground nuclear tests, similar to selected site for HLW disposal. Groundwater below NTS does not recieve recharge and is greater than 1000 feet below land surface.	Immediately implementable with approvals and some treatment to meet transportation requirements and WAC.	Capital - mod/high O&M - mod
		Private Repository such as Envirocare in Utah	Removes waste from Idaho, so has excellent long term effectiveness; in terms of the Snake River aquifer. However, currently high activity levels and large TRU nuclide content not accepted. Packaging depends on treatment process and waste form waste acceptance criteria (WAC). Treated waste effectively assayed to verify waste meets this WAC.	Immediately implementable with approvals and some treatment to meet transportation requirements and WAC for some of the LLW types and Low Specific Activity (contaminated soils). Approvals by DOE and possibly congress for TRU wastes.	Capital - very low O&M - low

Return to pit or trench or new "SDA" at INEL	Leaves treated waste at INEL location covered and capped in a conventional manner with a monitoring systems for subsurface migration of contaminants similar to those used in all capping and containment alternatives. Limits and WAC have not been set for SDA wastes. The effectiveness of this disposal option partially dependent on treatment option, specific radionuclide and containment features of any new repository. Effectivness partially depends on treatment if any of returned waste, but mainly on containment covereing and will be similar to that of the capping options. Thermal treatment fixes but does not eliminate the TRU or heavy metals however, putting them in IEB or glass form improves the confinement similar to what would be experienced at WIPP. Short term effectiveness again depends on interim storage option due to the lead time to process. VOC are absorbed in off gas or destroyed if thermal treatment is used. Thermal treatment and disposal does not remove gamma contamination; however, the mobility of non-carbonate contaminants should be reduced from their present state. For carbon-14 carbonate material, thermal treatments have poor short term effectiveness because carbon dioxide is released and difficult to capture in the off gas system.	Thermal treatment systems not demonstrated for mixed waste. There are several "thermal treatment options" which are being investigated by both EM-30 (IWPF), EM-50 (Plasma Hearth), EM 40 (pit-9) which should be implementable by 1998. Reinturnment or new pit construction immediately implementable. Reburying the processed waste in existing LLW area is a simple construction project.	Capital - mod O&M - low mod

General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability/Availability	Cost 2
Retrieval, Ex-Situ Processing, Disposal	Retrieval	Refer To Above Retrieval Options; Ex Situ Treatments Are Relatively Independent Of Retrieval Method			
	Non-thermal Waste Treatment	Dissolution of waste, Ferrate Precipitation	Effective for separating and concentrating insoluble heavy metals (both hazardous and radioactive). After removal of precipitate most debris is non hazardous and contamination levels for TRU are less than the LLW 10 nCi/gm criterion. Not effective on most Reactor Waste COC or Volatile organics. Recycling of treatment liquids after nuclide removal and chemicals minimize secondary waste stream.	Technology is proven and commercially available for process waste streams. Not proven on retrieved debris.	Capital - mod O&M - mod
		Chemical Dechlorination	Effective for detoxification of chlorinated organics. Coprocessing using another process for metal removal could provide TRU/Heavy metal treatment. Reactor Waste C-14 and Tc-99 not effectively concentrated. Organic I-129 might be removed. Recycling of treatment liquids after nuclide removal and chemicals minimize secondary waste stream.	Technology has been demonstrated for non radiological process streams. Unproven for TRU high field applications.	Capital - mod O&M - low/mod
		Dissolution of Waste, Magnetic Separation	Effective for separating and concentrating soluble or finely divided magnetically susceptible heavy metals (both hazardous and radioactive). After removal, remaining debris is non hazardous and contamination levels for TRU are less than the LLW 10 nCi/gm criterion. Not effective on most Reactor Waste COC or Volatile organics. Recycling of treatment liquids after nuclide removal and chemicals minimize secondary waste stream.	Technology has been demonstrated for non radiological non waste process streams. Unproven for TRU separation, high field applications, buried waste types.	Capital - low/mod O&M - low/mod
		Solution/chemical Surface decontamination of large objects, debris and metal waste	Conventional surface waste decontamination technologies are most effective for TRU/heavy metal removal from large hard objects surfaces. C-14 and Tc-99 contamination is generally within objects thus this treatment ineffective for concentrating these Reactor Waste COC. Organics and I-129 are not conducive to this treatment and may generate a mixed waste. Reducing TRU contamination levels to 10 nCi/gm is only effective if hazardous organics and heavy metals have been removed to make the remaining debris LLW. Recycling of wash treatment liquids and chemicals mandatory to minimize secondary waste stream. Operation must be remote for highly contaminated objects.	General decontamination commercially available. Never used for TRU removal in high field environment. Individual solution washes use proven technologies, combined washes with different solutions are not. Final design and construction for TRU accomplishable within CERCLA time limitations. Reactor Waste COC removal not demonstrated.	Capital -mod O&M - low/mod
		CO2 blasting Surface decontamination of large objects, debris and metal waste	Innovative surface decontamination technologies often more effective for TRU/heavy metal removal from large hard objects surfaces than solutions. C-14 and Tc-99 contamination is generally within objects thus this treatment less likley to bring these to the surface and is ineffective for concentrating these Reactor Waste COC. Organics and I-129 are condensed during treatment and might be removed. No recycling needed and no secondary waste generated. Operation must be remote for highly contaminated objects.	Advanced decontamination commercially available. Proven for cleaning lead bricks. Never used for TRU removal in high field environment but might be easier to remotize. Final design and construction for TRU accomplishable within CERCLA time limitations. Reactor Waste COC removal not demonstrated.	Capital -mod O&M - low/mod
		Soil Washing	Soil washing technologies are effective for TRU/heavy metal, soluble salts and organic removal from soil in a multi step, multisolution, sequential process. Effective washing depends on the binding of contaminant to the soil. C-14 carbonates would be aerosolized by any acidic wash process. Tc-99 contamination is anionic and might not be removed with other metals (usually are cationic). Organics are usually washed with surfactants or other organics which might be ineffective for inorganics. Reducing TRU contamination levels to 10 nCi/gm is only effective if hazardous organics and heavy metals have been removed to make the remaining debris LLW. Recycling of wash treatment liquids and chemicals minimize secondary waste stream. Operation must be remote for highly contaminated objects.	Technology is proven, commercially available for organic removal from soil. TRU soil washing proven on some soils. C-14, Tc-99 removal unproven. Multicomponent washing unproven.	Capital - mod O&M - mod
		Hydraulic Cement based Solidification	Effective for fixing dusts, TRU/heavy metals, C-14 carbonates, Tc-99 metals, I-129 salts. Ineffective for volatile, chlorinated organics. Coprocessing using another process for organic removal could provide hazardous delisting. 2X Volume increase. Some shielding for Reactor Waste COC. No nuclide removal. Little or no secondary waste stream.	Technology is commercially available. Waste shredding required. Formulations have been demonstrated for Reactor Waste streams. Organic formulations unproven. Customized formulations must be proven for most radiological process streams. Unproven for shredded debris multicomponent applications.	Capital - low O&M - low
		Polymeric Encapsulation	Effective for encapsulating dusts, TRU/heavy metals, C-14 carbonates, Tc-99 metals, I-129 salts. Ineffective for organics. Coprocessing using another process for organic removal could provide hazardous delisting and make process useful for all COC. 2X Volume increase. Ineffective for high thermal loading Reactor Waste COC. No nuclide removal. Little or no secondary waste stream.	Technology has been demonstrated for radiological debris and waste process streams. Unproven in high fields, with high thermal loading wastes. Unproven for shredded debris multicomponent applications.	Capital - low O&M - low
		Super Critical Water Oxidation	The best method for destruction of both dissolved or associated (DNAPL) organics in groundwater even at trace concentrations. High pressures allow complete destruction at moderate temperatures. Coprocessing using another process for precipitating trace metal removal could provide TRU/Heavy metal treatment. Reactor Waste C-14 currently is not in the ground water but trace dioxide if released can be captured with a cryogenic trap. Tc-99 oxide volatility is minimal in this process. I-129 is easily removed.	Wet oxidation used commercially for hazardous wastewater treatment. Technology has been demonstrated for non radiological process streams. Unproven for TRU, C-14, Tc99 containing liquids. High field operation not likely. Low worker exposure.	Capital - mod O&M - mod

Ex Situ (pumped) Groundwater Treatment	Aerobic Bioremediation	Effective for destruction of most organics dissolved or associated (DNAPL) with groundwater. Most effective means to destroy nitrates in groundwater. Operates with low energy consumption only requiring aeration at room temperature. Some bacteria and perform coprocessing precipitating trace metals (TRU/Heavy metal) while organics are decomposed. Reactor Waste C-14 currently is not in the ground water but trace dioxide if released can be captured with a cryogenic trap if above release limits. Tc-99 oxide volatility is minimal in this process and along with I-129 might be precipitated.	Technology has been demonstrated for low level radiological waste process streams at Oak Ridge National Lab. Requires large lagoons. Unproven for TRU separation, limiting C-14 dioxide release. Not possible in high field applications though these are unlikely in groundwater. Low energy consumption and worker exposure	Capital - mod O&M - low
	Ultraviolet Catalytic Destruction	Effective for destruction of many dissolved organics. Not proven for DNAPL in groundwater. Operates with moderate energy consumption. Catalysis selection and preventing posing important factors. No influence on precipitating trace metals (TRU/Heavy metal) while organics are decomposed. Reactor Waste C-14 currently is not in the ground water but trace dioxide if released can be captured with a cryogenic trap if above release limits. Tc-99 oxide volatility is minimal in this process and along with I-129 might be precipitated.	Technology has been demonstrated for non radiological process streams for select organic destruction. Unproven for TRU /heavy metal interferences, and limiting C-14 dioxide release. Can be used in high field applications though these are unlikely in groundwater. Energy consumption variable. Achieving ultra low level discharge while maintaining high though puts are not proven.	Capital - low/mod O&M - low
	Air Stripping	Effective for removal of more volatile dissolved organics. Not proven for dense nonaqueous phase liquids in groundwater. Operates with moderate energy consumption and requires some absorption or treatment of vapors. The following are currently not in the ground water itself and are not addressed by this treatment. No influence on precipitating trace metals (TRU/Heavy metal) or removing dissolved salts which might contain reactor waste C-14 carbonates/dissolved trace dioxide, Tc-99 oxide and I-129.	Technology has been demonstrated for non radiological process streams for selected organic removal. Unproven for limiting C-14 dioxide release. Can be used in high field applications though these are unlikely in groundwater. Energy consumption low. Achieving ultra low level removal while maintaining high though puts not proven for some of the organics at the SDA.	Capital - mod O&M - mod
	Activated Carbon Absorption	Most effective for removal of non polar halogenated dissolved organics and molecular I-129. Not proven for dense nonaqueous phase liquids in groundwater. Operates with low energy consumption. Requires some recycle or disposal of activated carbon. Ultra low levels at high flow rates might be difficult to achieve. The following are currently not in the ground water itself but might addressed be remediated with the addition of ion exchange resins or other absorbents: trace metals (TRU/Heavy metal) or dissolved salts which might contain reactor waste C-14 carbonates/dissolved trace dioxide, Tc-99 oxide and I-129 salts.	Technology has been demonstrated and implemented at Superfunds sites for non radiological process streams for selected organic removal. Unproven for C-14 dioxide removal. Can be used in high field applications though these are unlikely in groundwater. Energy consumption low. Achieving ultra low level removal while maintaining high though puts not proven for some of the organics at the SDA.	Capital - low/mod O&M - mod
	Ultrasound Destruction of Organics	Innovative technology for destruction of some dissolved or associated organics (Dense non Aqueous Phase Liquids, DNAPL) in groundwater. Ambient pressures and temperatures require less energy than thermal stripping or SCWO. Coprocessing using another process for precipitating trace metal removal could provide TRU/Heavy metal treatment. Reactor Waste C-14 currently is not in the ground water but trace carbon-14 dioxide if released can be captured with a cryogenic trap. Tc-99 oxide volatility is minimal in this process. I-129 is easily removed in the oxide.	Technology was rejected due to lack of effectivenss and availability. It is still being developed for high pumping volumes and achieving high destruction efficiences. Unproven for TRU, C-14, Tc-99 containing liquids. High field operation not likely. Low worker exposure to chemicals and radionuclides.	Capital - mod O&M - mod
	Distillation/ Stripping/ Evaporation	Most effective technology for complete groundwater clean up of both organics, DNAPL and dissolved salts. Operates with high energy consumption especially when dealing with large volumes of water with low concentrations of contaminants as is currently the case with SDA groundwaters. Requires some absorption or treatment of vapors. The following are currently not in the ground water itself but are addressed by this treatment. Dissolved trace metals (TRU/Heavy metal) remain after evaporation as due other dissolved salts which might contain reactor waste C-14 carbonates/dissolved trace dioxide, Tc-99 oxide and I-129 iodides. Remaining salts, scales, and, organics driven off, may require further treatment and must bedisposedof.	Technology is readily implementable and has been demonstrated for drinking water purification . Unproven for limiting C-14 dioxide release. Can be used in high field applications though these are unlikely in groundwater. Energy consumption high and a large storage area required for evaporation.	Capital - mod O&M - mod
Thermal Waste Treatment	Low Temperature Joule Heated Ceramic Melter	Technology currently in use for high level waste and soil-washing residues. Low temperature nature of technology produces less effective vitrified product than other thermal vitrification technologies, due to more vitreous, less crystalline nature of final waste form. Product durability still strong, however. Low temperature ceramic melters typically have strict limits on both compositional and redox variability. As a result, use may require significant pretreatment of the feed stream. Also requires significant pretreatment of waste materials (i.e. shredding) to make certain that the waste materials can be delivered in a manner that does not require major process upset. Less volatility issues than other thermal vitrification processes, due to lower processing temperature. Removes C-14 from the waste, without offgas capture, which may cause an air emission concern. Iodine and technetium concerns expected to be similar to in situ vitrification concerns.	Immediately implementable, although some waste compositional analysis may still be needed if the buried waste streams have extensive variations in potential waste form composition. Further demonstration of pre-treatment shredding technology needed for TRU waste.	Capital - Mod/high O&m - High
	High Temperature Joule Heated Ceramic Melter	Similar to low temperature joule heated melters, but with higher process temperatures. Higher process temperatures result in improved product durability, due to more crystalline nature of waste form. Increased volatility concerns over low temperature melters, but can be engineered around via offgas design. High process temperature allow engineering around redox limitations of low temperature melters, increasing compositional variability. However, joule-heated nature of technology still results in compositional variability concerns. Effect of low level waste drivers (C-14, Tc-99, I-129) similar to other vitrification processes.	Demonstrated via pilot- and bench-scale tests, on non-radioactive components only. Still needs radioactive testing. Requires higher amount of offgas design than low temperature melters, but more redox variable, increasing compositional variability.	Capital - Mod/high O&m - Mod/high
	Plasma Arc Melters	Operable in both AC and DC mode, in both a transferred and non-transferred mode. Compositional limitations associated with Joule-heated melters are not present with plasma arc melters, due to non-joule heating requirments for plasma. Redox limitations associated with low temperature melters are also eliminated, due to higher processing temperatures in plasma arc melters. Plasma arc melters are typically less energy efficient than joule heated melters, due to the presence of an arc. The plasma arc also results in more volatilization than with Joule-heated melters. Plasma arc melters are less flexible than plasma torch melters, but can be scaled up to higher throughput volumes than plasma torch melters. Plasma arc melters are usually more energy efficient than plasma torch melters, due to arc length. Effect of LLW drivers similar to other vitrification processes.	Technology commercially available, substantial operating history in steel industry, but not yet demonstrated for mixed waste application. Both DC and AC arc melters demonstrated on pilot-scale, for non-radioactive applications. Full-scale radioactive demonstrations are scheduled for FY-95 and FY-96. Plasma arc melters are generally more applicable than plasma torch melters for large volume waste streams that have limited waste form variability (i.e., buried wastes, but not stored wastes). Issue of short-life for plasma arc torch can be eliminated by using carbon arc electrode (although this limits redox potential).	Capital - Mod/high O&m - Mod/high

Option	Description	Status	Cost
Plasma Torch Melters	Version of plasma arc melter where arc is blown out of electrode annulus, via gas pressure, forming a torch. Plasma torches generally have more degrees of movement than plasma arc melters, allowing the torch to be applied to sections of the waste slugs coming into the melt, rather than the melt pool itself. Waste form quality and process performance, compared to Joule-heated melters, is similar to that of other plasma arc melters. However, the torch has more redox flexibility than plasma arc melters, due to the ability to use oxygen as the carrier gas in the electrode annulus. Plasma torches also have less potential process upset than plasma arc melters, since the can direct their melting on portions of the waste before it falls in the melt, thereby limiting sudden offgas surges or melt compositional surges. Plasma torches also require less shredding pre-treatment than plasma arc melters. Not as scalable to high throughput volumes as plasma arc melters. Also more potential volatilization concerns, due to longer length of torch. Effect of LLW drivers similar to other vitrification technologies.	Technology commercially available, substantial operating history in steel industry, but not yet demonstrated for mixed waste application. Has been demonstrated in pilot-scale, for non-radioactive applications. Full-scale demonstrations scheduled for FY-95 and FY-96. Plasma torch melters are generally more applicable than plasma arc melters for large compositional variations of waste (i.e. stored wastes). May require more off-gas treatment than arc melter.	Capital - Mod/high O&m - Mod/high
Centrifugal Plasma Torch Melter	Plasma torch system with a complicated centrifugal delivery system that controls the volume of vitrified material released from the melt. Centrifugal system may have more maintenance and power backup concerns than other torch melters. Product quality, and volatilization potential similar to other torch melters. Effect of LLW drives similar to other vitrification technologies.	Radioactive demonstration tests on buried mixed wastes underway in FY-95 and FY-96. Moving parts in melter may increase maintenance concerns, require more utility backup than other melters, due to fact the power losses will cause the melter to empty. Moving parts may also have extra decontamination and decommisioning concerns. Torch-life (approximately 200 hours) also a concern.	Capital - Mod/high O&m - High

Disposal — Refer To Above Disposal Options. Ex Situ Treatments Are Able To Prepare Waste For Any Disposal Option. The Feasibility Of Some Disposal Options Might Change Depending On The Treatment

Pre Treatment, Retrieval, Ex-Situ Processing, Disposal

Retrieval — Refer to above Retrieval Options; Pre treatments are enhancements for Retrieval. Some as noted cannot be used with completely Manual Methods; Modifications for Smaller scale retrieval are possible for most Retrieval Methods

PreTreatment before retrieval for; Contamination Control and/or partial retrieval ie. - hot-spot "(highly localized source term) .

Option	Description	Status	Cost
Cryogenic Retrieval	Retrieval operation requires active contamination control. Effective in removal of entire contaminant source term for moist sludges and soils that cling together. Production rates scalable to 80 cu. yd. per day. Particulate contamination control of 50% over conventional retrieval achieved. Expected to be most effective method of preventing VOC volatility. Not particularly advantageous for reactor waste especially large objects. Remote maintenance and gamma hardened equipment and cameras might be required.	Demonstrated technology in buried waste TRU environment, production rate scalable to 80 yd3/day. Requires engineering refinements in LN2 efficiencies and retrieval techniques. Available technology from Houston TX; however would require modification for remote maintenance and gamma hardened equipment and cameras to handle reactor type wastes. Barrier technology is immediately available. Available as a temporary barrier technology;Commercially from available limited. Cryogenic technology available for VOC's under study at ORNL by with results in FY-95.	Capital - mod/high O&M - high
Grouted Waste Retrieval	Overburden removal for maximizes effectiveness to avoid contamination of surrounding soil. This option allows in-situ interim storage especially for "hot spots" until treatment/disposal options are identified. Provides the best interim storage in-situ for up to 20 years prior to retrieval. Excellent short and long term effectiveness as it entails complete removal of the hazard. Containment structure can remove VOC in charcoal filters. Is as effective as cryogenics at eliminating dust during retrieval but does not eliminate VOC release. Like Cryogenic applicable to hot spot retrieval Portland cement does warm up the waste which might drive off VOC's. Short term effectiveness better than cryogenic and grouting can be used as an interim treatment option. May require addition of ventilation system to remove VOC during grouting and retrieval. Cement provides some shielding in the case of Reactor Waste. This and the shielding of the overburden may decrease the need for remote grouting operation to avoid gamma dose to workers. Also retrieval equipment may require gamma hardening.	Proof-of-concept demonstrated as a particulate contamination control measure during retrieval. Grouting portion of the technology fully implementable; however, the retrieval technique needs more work to chose correct retrieval method, optimize the fracturing technique and refine grout formulation for TRU, reactor wastes and VOC solidification. Currently would require a ventilation system to remove the VOC's from the air. Any remotizing of drilling equipment and gamma hardening of retrieval equipment for Reactor Waste would require development though the chemical grout fracturing looks more promising than mechanical or explosives.	Capital - mod O&M - mod/high
Grout Subsidence Walls	Placing a wall around the hot spot using trenching, pressure grouting or jet grouting is effective at stopping both lateral water movement or intrusion and soil collapse into waste during retrieval The technique thus provides benefits for Hot Spot Retrieval to prevent wall sloughing which could add to the amount of waste excavated with the hot spot. Verification of wall integrity critical.	To be demonstrated at the INEL in FY-95 using novel grouts and jet grouting emplacement. Used commonly in the construction industry but not in a buried waste seam. In Situ walls are routinely used in construction industry. Technology commercially available for general construction and landfill type applications. Drilling, trenching technology is off the shelf.	Capital - mod O&M - mod

Sheet Piles	Effective in normal construction for preventing wall collapse and side control of water movement. Much less verification needed for evidence of adequate wall construction. Emplacement depends on knowledge of waste/pit boundaries. Obstructions like boulder and large objects (reactor wastes) will prevent full penetration.	Not demonstrated on SDA pits and trenches. Technology commercially available	Capital - low O&M - low
Cooperative Telerobotic Retrieval	Most effective technology for highly localized source terms with high fields or high safety or hazard rank. Effective for removing pretreated waste or large objects with high fields or high contamination potential. Operates well within a small area and removes source term while minimizing worker exposure. For "hot spot" retrieval a critical problem is locating the waste boundaries.	Fully implementable by Nov. 1995.	Capital - high O&M - mod
Waste Treatment	Refer to above Waste Treatment Options; Pre treatments might change the feasibility of some treatment options but are generally to enhance retrieval method; hot spot treatment only requires small treatment systems.		
Disposal	Refer to above Disposal Options, Pretreatment might eliminate further Ex Situ treatments or preparation for some disposal option. The Feasibility of Some options might Change Depending on Treatment Independent of Retrieval Method		

APPENDIX B

Bibliography of Technology Process Resource Documents From EPA Guidance Document for RI/FS Studies

Appendix B

Bibliography of Technology Process Resource Documents

I. Containment Technologies

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